The Glasgow Naturalist

Journal of the Glasgow Natural History Society

Volume 27 Part 3

With Supplement (Part 2): On the Wildside Revisited: 200 Years of Wildlife in the Glasgow Botanic Gardens.

Glasgow Natural History Society

(formerly The Andersonian Naturalists of Glasgow)

www.gnhs.org.uk

The Glasgow Natural History Society (GNHS) is a registered charity (SC012586) with about 250 members living in Glasgow, the West of Scotland, throughout the U.K. and overseas. GNHS arranges a full programme of events throughout the year in Glasgow and district and occasionally further afield (www.gnhs.org.uk/meetings.html). These are at both popular and specialist level, designed to bring together the amateur and the professional, the beginner and the expert. GNHS has its own library, provides grants for the study of natural history, and has microscopes and some field equipment that can be used by members. Further details about GNHS can be obtained by contacting the Secretary, The Glasgow Natural History Society, c/o Graham Kerr (Zoology) Building, University of Glasgow, Glasgow G12 8QQ, Scotland (E-mail: info@gnhs.org.uk).

The Glasgow Naturalist

The Glasgow Naturalist is published by the Glasgow Natural History Society ISSN 0373-241X. It was first issued in 1909 and is a peer-reviewed journal that publishes original studies in botany, zoology and geology, with a particular focus on studies from the West of Scotland. Full details of the journal can be found at www.gnhs.org.uk/gnat.html

A digital version of *The Glasgow Naturalist* from 1909 to the present is available at the Biodiversity Heritage Library at www.biodiversitylibrary.org/bibliography/38981#/summary
Hard copy back issues of the journal may be purchased by contacting GNHS.

Advice to contributors is given on the back inside cover of this edition and at www.gnhs.org.uk/documents/gn_information.pdf For questions or advice about submissions please contact the Editor Dr Iain Wilkie (E-mail: Editor@gnhs.org.uk) Craigeniver, Strachur, Argyll PA27 8BX.

Publications of the Glasgow Natural History Society

GNHS has published a number of books on the flora and fauna of Scotland. Details can be found at www.gnhs.org.uk/publications.html

Front cover River lamprey (*Lampetra fluviatilis*), caught in the River Endrick, Stirlingshire, Scotland and photographed in a holding tank, 19th September 2019. (Photo: Jonathan Archer)

Back cover Bee orchid (*Ophrys apifera*), Lendalfoot, South Ayrshire (Ailsa Craig in the background), Scotland, June 2019. See the Short Note by C.J. McInerny on pages 116-118 of this issue. (Photo: Chris McInerny)

The Glasgow Naturalist
Volume 27 Part 3

Edited by: Iain C. Wilkie & Christopher J. McInerny

Contents

The Glasgow Naturalist (2021) Volume 27, Part 3, 1-2

EDITORIAL

A perfect planet?

I.C. Wilkie

Institute of Biodiversity, Animal Health and Comparative Medicine, University of Glasgow, Glasgow G12 8QQ

E-mail: iain.wilkie@glasgow.ac.uk

Sir David Attenborough's latest TV series *A Perfect Planet* was shown in January 2021, at the start of the latest COVID-19 "lockdown". It provided spectacular insights into the lives of animals across the planet and was watched by a record audience: the BBC iPlayer saw the highest viewing figures in its history. The title was perhaps unfortunate: in January 2021 the global death toll due to COVID-19 had reached two million (Our World in Data, 2021), which seems to jar with the concept of a “perfect” planet; but then the BBC had announced the commissioning and name of the series as early as February 2019 (Waterson, 2019), months before the virus began to manifest itself. More seriously, the intended meaning of the title, which was emphasised repeatedly during different episodes, was that the Earth is perfect for the flourishing of life, the implication being that planetary properties and conditions could not be better for living things. This is disputable: for example, if the Earth had a greater planetary mass, it would have a larger surface area and be potentially able to support a greater biomass and greater biodiversity; there would also be more interior heating due to radioactive decay, resulting in a prolongation of the time the planet could stay habitable; it has been suggested that planets with up to twice the Earth's mass could be "superhabitable" (Schulze-Makuch *et al.*, 2020). These quibbles about the title aside, like all of David Attenborough's series, *A Perfect Planet* was a glorious celebration of biodiversity across the globe and to that extent helped viewers find, to use his own expression, "comfort and solace in the natural world" during a particularly stressful period (Cutmore & Barrett, 2021). *The Glasgow Naturalist* is also a celebration of biodiversity and, although it focuses on only one small corner of the planet, perfect or not, the editorial team hopes that it too will bring comfort and solace to our readership as we emerge from the pandemic.

At the time of writing (April 2021), a recent relaxation of COVID-19 restrictions in Scotland allows travel between Local Authority areas for the first time in almost four months. Those interested in the natural world once again have the freedom to explore without geographical constraint (as long as they get back home within the day!). When the editorial for the previous issue was written (March 2020), the first lockdown had just started. It was anticipated that the strict rules might encourage an interest in local natural history, because this was an activity that could be combined with the "one form of exercise" permitted per day. Research seems to have borne this out. An online survey of U.K. residents conducted by the University of Cumbria revealed that, during the first lockdown, all age groups spent more time daily in nature. "Listening to birdsong was the most common way adults noticed nature during lockdown (94% of respondents), followed by watching wildlife (87%) and taking time to notice bees or butterflies specifically (83%)" (Lemmey, 2020). In another online survey, 64% of residents of the state of Vermont, U.S.A. reported increased engagement in "wildlife watching" (Morse *et al.*, 2020).

Another expected outcome of the lockdowns was that, since there was less opportunity for outdoor and social activities, more articles would be written and submitted to the journal. However, despite an initial surge of submissions, this issue contains only three more articles than the previous, though this is due to an increase in the number of full papers from six to nine. The geographical range of the articles extends from Fair Isle to East Lothian and the Firth of Clyde, with islands being a theme: Fair Isle, the Isle of May, and the Isle of Cumbrae, the last represented by two articles one of which includes an important bibliography of research associated with Kames Bay. The diversity of taxa covered is as great as in the previous issue, but different. Although there is the same imbalance between animals (20 articles) and plants+fungi (three articles); vertebrates are better represented in this issue, with eight articles on fish, birds or mammals, in comparison with 12 on invertebrates. Some of the articles are highly topical. A paper on mountain hares (*Lepus timidus*) in the Lammermuir Hills (Pettigrew, 2021) was received in the month when it became illegal in Scotland to intentionally kill, injure, or take mountain hares at any time without a licence. Two articles refer to unusual sightings of bottlenose whales (*Hyperoodon ampullatus*) in the Firths of Clyde and Forth, thereby adding to the evidence that U.K. waters are being visited by an increasing number and diversity of whales: as recently as early April of this year a sei whale (*Balaenoptera borealis*) was spotted in the Firth of Forth (Hutchison, 2021), only the fifth recorded sighting in Scottish waters (NBN Atlas, 2021).

Two of the full papers and six of the short notes comprise Part 2 of the supplement *On the Wildside Revisited: 200 years of Wildlife in the Glasgow Botanic Gardens* the first part of which appeared in Volume 27, Part 1. This series gives an excellent indication of the diversity of organisms that can be found in a fairly central city park where almost all habitats and substrates owe their existence directly or indirectly to human agency, and which endured over a hundred years of severe air pollution during the industrial trajectory of the city. Weddle & Downie (2021) point out that, although 1,384 species have been recorded in Glasgow Botanic Gardens, some groups of organisms are seriously under-reported, particularly protozoans, algae, slime moulds and prokaryotes (e.g. bacteria). Whilst the investigation of most of these groups is feasible only for professional specialists with access to laboratory facilities, the relative neglect of freshwater habitats and their macroscopic denizens leaves some scope for amateur naturalists to make a contribution. The final articles in the *On the Wildside Revisited* series will be published in Volume 27, Part 4.

In this issue we also pay tribute to an outstanding professional naturalist and long-standing member of Glasgow Natural History Society (GNHS). John Mitchell was for 27 years the reserve warden for the Loch Lomond National Nature Reserve. During his career he contributed around 3,500 records to the database of the Botanical Society of Britain and Ireland and wrote numerous articles, including around 50 for *The Glasgow Naturalist*. He also wrote the highly praised book *Loch Lomondside*, No. 88 of Collins New Naturalist Library, which was published in 2001. He received an Honorary MA from the University of Stirling and the Fellowship of the Zoological Society of Scotland and was recently awarded Honorary membership of GNHS. John Mitchell was a star in the firmament of Scottish natural history.

ACKNOWLEDGEMENTS

As always, I am very grateful to Chris McInerny, Ruth Maclachlan and Richard Weddle for their assistance in the editing, assembly and website presentation of the journal, and to the external experts whose critical evaluation of submitted manuscripts is crucial in maintaining the journal's scientific standards. The external reviewers for this issue were (in alphabetical order): M. Culshaw, N. Davison, R.W. Furness, J.C. Gordon, D. Gow, S.J. Gregory, E.G. Hancock, C. Hart, J.N. Hedger, J.W. Heiss, D. Lang, M. Law, I. Macdonald, R. Miller, S. Newey, D. Orr-Ewing, S. Shanks, A.J.A. Stewart, P. Tatner, J. Taylor, I. Thornhill, J.G. Wilson, R. Yahr and one other who preferred to remain anonymous.

REFERENCES

Cutmore, J. & Barrett, A. (2021). Sir David Attenborough's new series *A Perfect Planet*. *BBC Science Focus* https://www.sciencefocus.com/nature/in-pictures-sir-david-attenboroughs-new-series-a-perfect-planet/ Accessed 21st April 2021.

Hutchison, C. (2021). Rare Sei Whale spotted in Firth of Forth, South Queensferry. *The National* April 15th.

Lemmey, T. (2020). *Connection with Nature in the UK during the COVID-19 Lockdown.* University of Cumbria, Carlisle. https://insight.cumbria.ac.uk/id/eprint/5639/ Accessed 19th April 2021.

Morse, J.W., Gladkikh, T.M., Hackenburg, D.M. & Gould, R.K. (2020). COVID-19 and human-nature relationships: Vermonters' activities in nature and associated nonmaterial values during the pandemic. *PLoS ONE* 15(12): e0243697. https://doi.org/10.1371/journal.pone.0243697

NBN Atlas (2021). *Balaenoptera borealis* Lesson, 1828. https://records.nbnatlas.org/occurrences/search?q=lsid:NBNSYS0000005162 Accessed 20th April 2021.

Our World in Data (2021). Cumulative confirmed COVID-19 death and cases, World. https://ourworldindata.org/grapher/cumulative-deaths-and-cases-covid-19?country=~OWID_WRL Accessed 21st April 2021.

Pettigrew, G.W. (2021). When to count? Indices of population size for mountain hares of the north-west Lammermuir Hills. *The Glasgow Naturalist* 27(3), 6-13. https://doi.org/10.37208/tgn27301

Schulze-Makuch, D., Heller, R. & Guinan, E. (2020). In search of a planet better than Earth: top contenders for a superhabitable world. *Astrobiology* 20, 1394-1404. https://doi.org/10.1089/ast.2019.2161

Waterson, J. (2019). BBC fights to stop David Attenborough being poached. *The Guardian* 8th February.

Weddle, R.B. & Downie, J.R. (2021). On the Wildside 2: what the Glasgow Botanic Gardens *Wildside* project has achieved and what remains to be done. *The Glasgow Naturalist* 27(3), 68-71. https://doi.org/10.37208/tgn27325

The Glasgow Naturalist (2021) Volume 27, Part 3, 3-5 https://doi.org/10.37208/tgn27305

FULL PAPERS

A review of bordered brown lacewing *Megalomus hirtus* (Neuroptera: Hemerobiidae) distribution in Scotland

S. Burgess[1] & N.A. Littlewood[2]

[1]Buglife, Balallan House, 24 Allan Park, Stirling FK8 2QG
[2]SRUC, Craibstone, Aberdeen AB21 9YA

[1]E-mail: suzanne.burgess@buglife.org.uk

ABSTRACT
In the U.K., the bordered brown lacewing (*Megalomus hirtus*) is associated with aphids and other insects on wood sage (*Teucrium scorodonia*) growing on rocky exposed slopes. The species is widely distributed across northern and central Europe. However, before 2019 it was recorded from only three sites in the U.K., all in Scotland, at Holyrood Park in Edinburgh, and at Muchalls and St. Cyrus, both in Aberdeenshire. Surveys in 2019 discovered the lacewing in a new area of Holyrood Park and at several new sites from Stonehaven to Portlethen village in Aberdeenshire. Only adults were recorded, and all were collected from wood sage. The surveys have also identified other areas and sites that should be visited to determine the distribution of the bordered brown lacewing in Scotland.

INTRODUCTION
The bordered brown lacewing *Megalomus hirtus* (L., 1761) (Fig 1.) is approximately 1 cm in length and can be identified by the wide costal space on both forewings (Plant, 1997). Another key character used to identify this species is the five (sometimes six or seven) radial veins that branch from the humeral vein on both forewings. The patterning and hair on its wings and body are not diagnostic features, as this species looks similar to other species of brown lacewing in the Hemerobiidae family.

Adults of bordered brown lacewing have been recorded from June to August, although they may be active earlier and later depending on the local climate (Plant, 1994; Littlewood & Stockan, 2013). Adults appear to spend most of the day deep amongst vegetation and are unwilling to move, even when disturbed (Plant, 1997; Nielsen, 2015).

Adult females lay each egg individually and on the underside of the leaves of wood sage and potentially other plant species (Nielsen, 2015). The larval stage has been known to last up to four years and, when ready to pupate, they will overwinter in their cocoons to emerge as adults the following year. In the U.K. this species is associated with aphids and other insects on wood sage growing on rocky hill-sides and under cliffs (Plant, 1994). In Europe it may not be confined to this plant having been recorded from hazels (*Corylus* spp.) and other plant species (Plant, 1997; Nielsen, 2015).

Fig. 1. Bordered brown lacewing (*Megalomus hirtus*) adult (length 1 cm) on wood sage (*Teucrium scorodonia*), Skatie Shore, Aberdeenshire, Scotland, 1st July 2019. (Photo: S. Burgess)

Although widely distributed across mainland Europe, in the U.K. this species has a very restricted distribution, being found only in Scotland. Before 2019, there were only three known sites for the species in Scotland, at Holyrood Park in Edinburgh, and in Aberdeenshire at Doonie Point by Bridge of Muchalls and St. Cyrus (Burgess & Lindsay, 2019). Although there are some reports from other sites, none is adequately documented. Indeed a hectad near Aberdeen, NJ80, that appeared in the distribution atlas covering this group (Plant, 1994) has now been removed from the Lacewing and Allies Record Scheme database, as it was likely included due to confusion with Muchalls (Littlewood, 2018).

As a result of its restricted distribution in Scotland the species is on the Scottish Biodiversity List (SBL) as a priority species. Given the poor knowledge of its current

distribution there is a pressing need to determine its status in the U.K. This paper provides information on the results of surveys conducted in Holyrood Park, Edinburgh, in Aberdeenshire, and in other sites, which gives an indication of the current status of the species in Scotland.

SURVEYS

Holyrood Park

Adults of the bordered brown lacewing have periodically been recorded from their stronghold at Holyrood Park, with most recent records in 1980, 1995, 2015 and during the current Buglife led surveys in 2018 and 2019 (Littlewood & Stockan, 2013; Smith & Burgess, 2015; Burgess & Lindsay, 2019; Lemon & Burgess, 2019). During the survey in 2015, one adult was recorded on 30th June on a rocky slope near the summit of Arthur's Seat (NT27527288) (Smith & Burgess, 2015). With only one adult being recorded in 1995 and then this singleton over a three-month sampling period in 2015, Buglife, with funding from Scottish Natural Heritage (SNH), organised surveys with members of the public in 2018 and again in 2019. Permission for the surveys was granted by Historic Environment Scotland (HES) who manage the park and SNH, as Holyrood Park is a designated Site of Special Scientific Interest (SSSI).

During the survey in 2018, a total of 14 adults was recorded in early June along the rocky outcrops of Salisbury Crags from NT26887348 to NT26747317 (Lemon & Burgess, 2019). The main path along Salisbury Crags has since been closed to members of the public for health and safety reasons and surveys in 2019 focused on other areas of Holyrood Park. In 2019, a further 12 adults were recorded in late June and early July at rocky outcrops below St. Anthony's Chapel at NT27407370 and NT27577370 (Burgess & Lindsay, 2019). Whinny Hill (NT27717318) within Holyrood Park was also visited in July 2019 and although the area has plentiful wood sage, no lacewings were recorded (Burgess & Lindsay, 2019). During both visits in 2019 a ranger from HES was present and learned how to survey for this species. The rangers aim to continue monitoring for the species and determine if the lacewing is found across a much larger area of Holyrood Park.

Aberdeenshire

Muchalls in Aberdeenshire has historic records of the species up to 1916, when a short series of adults was taken (King, 1917). There were no further records until one adult was taken by Doonie Point, Muchalls (NO90159095) on 7th July 2018 (Littlewood, 2018).

The area at Doonie Point was visited by the authors on 8th May 2019 to look at the condition of the habitat and identify new areas for a public survey to be held when adults are known to be active later in the summer (Burgess & Lindsay, 2019). It was decided to hold this public survey at a coastal site slightly further south of Doonie Point (and with easier access for the public) at Skatie Shore and Perthumie Bay. This area is just north of the town of Stonehaven and is part of Garron Point SSSI, a rocky promontory with adjoining coastal strips that have steep grassy cliffs, vegetated shingle and areas of species-rich grassland. The site has been designated as an SSSI to protect a combination of geological and biological features including the SBL priority species narrow-mouthed whorl snail (*Vertigo angustior*) and northern brown argus butterfly (*Aricia artaxerxes*). The public survey held here on 1st July recorded ten adults of the bordered brown lacewing from several patches of wood sage from NO89038780 to NO89048813 (Fig. 2) (Burgess & Lindsay, 2019).

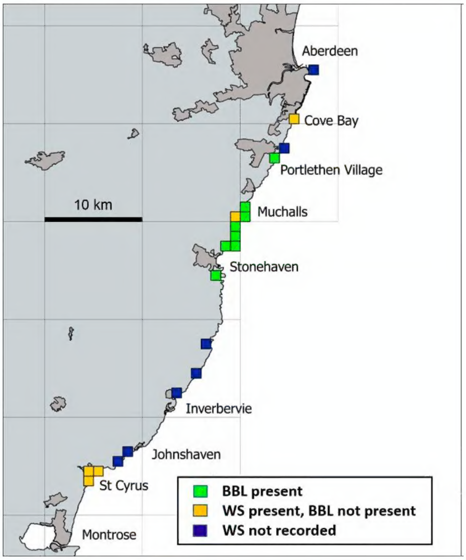

Fig. 2. Map of part of east Aberdeenshire, Scotland showing results of surveys in 2019. BBL, bordered brown lacewing (*Megalomus hirtus*); WS, wood sage (*Teucrium scorodonia*).

After the public survey on 1st July, N.A.L. travelled north of the bay to search other areas of wood sage found on rocky outcrops along the coast and successfully found an adult at NO89288908 (Fig. 2). The war memorial just south of Stonehaven was visited later on the same day and an adult was recorded on wood sage at NO87808481 (Fig. 2). Later that week, N.A.L. recorded adults of the bordered brown lacewing along other areas of the coast and identified other sites that supported wood sage where the lacewing was not recorded but should be revisited (Fig. 2). At Doonie Point (NO90139094) two adults were recorded in the same area as they were recorded in 2018 (Fig. 2). Another adult was recorded at Portlethen Village (NO93349605) (Fig. 2) which only had small patches of wood sage that were difficult to access being on steep slopes. Another was recorded just outside of Muchalls village (NO90259165) (Fig. 2). A further four adults, all from the same clump of wood sage, were recorded at Craigeven Bay (NO88748752) (Fig. 2), a short way south of Garron Point.

Other sites
There are historical records of bordered brown lacewing from another coastal site at the southern extremity of Aberdeenshire, at St. Cyrus National Nature Reserve, where the species was last recorded in 1935 (Plant, 1997). This site was visited during surveys in 2015, 2018 and 2019, although each has been unsuccessful in recording the bordered brown lacewing (Smith & Burgess, 2015; Lemon & Burgess, 2019; Burgess & Lindsay, 2019). Wood sage is plentiful across this National Nature Reserve and the habitat is similar to where the lacewing has been recorded along the Aberdeenshire coast with several patches of wood sage on exposed rocky outcrops.

Blackford Hill Local Nature Reserve within the Hermitage of Braids in Edinburgh was also visited during surveys in 2015, 2018 and 2019 (Smith & Burgess, 2015; Lemon & Burgess, 2019; Burgess & Lindsay, 2019). Blackford Hill is 3 km south-west of Holyrood Park and supports similar habitat, although within a much smaller area. There are several patches of wood sage, some of which are on exposed rocky cliffs. Surveys at this site were unsuccessful in recording the bordered brown lacewing although the quality of habitat that could support the species was assessed and found to be poor due to shading by gorse (*Ulex europaeus*). This invasive plant is currently being controlled and removed by the rangers who manage the site, which will significantly improve the quality of habitat for the lacewing (should it be present here) and other wildlife.

CONCLUSION
As a result of these surveys, the bordered brown lacewing has been discovered at several new sites along the Aberdeenshire coast and in Holyrood Park; and additional potentially suitable areas have been identified for future surveys. It is important to continue the monitoring of this species to determine its health and distribution in Scotland, and to ensure its long-term survival.

ACKNOWLEDGEMENTS
Buglife would like to thank SNH for providing funding to allow surveys for the bordered brown lacewing that have helped rediscover this rare species in Scotland. We would also like to thank all the volunteers who have participated in the surveys.

REFERENCES
Burgess, S. & Lindsay, J. (2019). Bordered Brown Lacewing Project Report. *Buglife*. https://cdn.buglife.org.uk/2019/12/Bordered-brown-lacewing-report-2019-final.pdf Accessed 29th April 2020.

King, J.J.F.X. (1917). Occurrence of *Megalomus hirtus* L. in Kincardineshire. *Entomologist's Monthly Magazine* 53, 87.

Lemon, A. & Burgess, S. (2019). Bordered Brown Lacewing Project Report. *Buglife*. https://cdn.buglife.org.uk/2019/07/Bordered-brown-lacewing-report-2018-final.pdf Accessed 29th April 2020.

Littlewood, N.A. (2018). *Megalomus hirtus* (L., 1761) (Neur.: Hemerobiidae) rediscovered in Aberdeenshire and investigation of an old record. *Entomologist's Record and Journal of Variation* 130, 274- 276.

Littlewood, N.A. & Stockan, J.A. (2013). Surveillance of priority terrestrial invertebrates in Scotland. *Scottish Natural Heritage Commissioned Report* No. 609. p 115-116. https://www.nls.uk/e-monographs/2013/609.pdf Accessed 29th April 2020.

Nielsen, O.F. (2015). *Danmarks Netvinger*. Apollo Books, Denmark.

Plant, C.W. (1994). *Provisional Atlas of Lacewings and Allied Insects (Neuroptera, Megaloptera, Raphidioptera and Mecoptera) of Britain and Ireland*. Biological Records Centre, Huntingdon.

Plant, C.W. (1997). A key to the adults of British lacewings and their allies. *Field Studies* 9, 179-269.

Smith, M. & Burgess, S. (2015). Rediscovering the Bordered brown lacewing (*Megalomus hirtus*). A survey in Holyrood Park SSSI. *Buglife*. https://cdn.buglife.org.uk/2019/07/Final-Bordered-brown-lacewing-report-MikeSmith_0.pdf Accessed 29th April 2020.

The Glasgow Naturalist (2021) Volume 27, Part 3, 6-13 https://doi.org/10.37208/tgn27301

When to count? Indices of population size for mountain hares of the north-west Lammermuir Hills, Scotland

G.W. Pettigrew

20 Kings Park, Longniddry, East Lothian EH32 0QL

E-mail: pettigrewgraham@gmail.com

ABSTRACT
Surveys with binoculars at two different times of day and in various months of the year, along with camera trap studies of diel activity patterns, were used to inform an appropriate period to count mountain hares (*Lepus timidus*) on managed red grouse (*Lagopus lagopus*) moorland of the Lammermuir Hills, south-east Scotland. Factors affecting the numbers of hares counted were time relative to sunrise, the presence of winter coat colour and reproductive behaviour in spring. Counts of hares in March and April starting one hour before dawn were used as an index of population size of the mountain hare over three years of observations on three hill-tops, with densities of 23-33 hares km^{-2}. The number of hares seen was stable or rose slightly over the three years despite a partial cull on one of the hills. In support of suitability of the timing of surveys used, camera trap studies revealed that the period around dawn in March and April was associated with high levels of hare activity.

INTRODUCTION
The mountain hare (*Lepus timidus*) is a native mammalian relict species of the last ice age in the alpine regions of the Cairngorm mountains of Scotland (Angerbjörn & Flux, 1995). This habitat differs from the preference for boreal forest in the bulk of its Eurasian range. In the 19th century the mountain hare was introduced as a game animal onto the heather moorland of shooting estates and these transplant populations persist, particularly in the north-east and south-east of Scotland (Flux, 1970; Patton *et al.*, 2010). Even with the killing component associated with sport shooting and population control in these managed environments, the mountain hare can thrive because of the encouragement of young heather (*Calluna vulgaris*) growth and the elimination of ground predators (Hewson, 1984).

However, the number of mountain hares counted on a non-random sample of heather moorland and alpine sites in north-east Scotland between 1954 and 1998 declined slowly by about 5% per annum (Watson & Wilson, 2018). This was attributed to loss of habitat, for example due to reforestation. From 1998 onwards, a much steeper decline in numbers was observed of around 30% per annum, down to levels less than 1% of those observed at the start of the study.

Watson & Wilson (2018) attributed this decline to extensive mountain hare culling by the shooting estates, which was done in the belief that this practice helps to limit the spread of the louping-ill virus (*Flavivirus* sp.) to red grouse. Mortality in red grouse infected with the louping-ill virus can be as high as 78% under laboratory conditions (Reid, 1978). The virus is carried by the sheep tick (*Ixodes ricinus*) and the tick can survive on wildlife hosts such as red deer (*Cervus elaphus*) and mountain hare (Jones *et al.*, 1997). On moorland with both domestic sheep (*Ovis aries*) and wildlife, transmission of the virus is therefore complex. Laurenson *et al.* (2003), found that the prevalence of louping-ill virus in young red grouse fell when mountain hares were culled to low densities. However, several features of the Laurenson study were unusual and other field studies and modeling results have been thoroughly considered by Harrison *et al.* (2010) and Gilbert (2016) with the conclusion that when red deer and sheep are present as tick hosts, the mountain hare makes little contribution to the prevalence of the disease in the majority of managed moorland. Despite that evaluation of the evidence, extensive culling of mountain hare has persisted. With particular relevance to this paper, louping-ill virus has not been detected in the Lammermuir Hills.

The mountain hare in the U.K. was protected by an EC Habitats directive (Council of the European Union, 1992). This directive required a government to maintain the animal in a "Favourable Conservation Status", a phrase interpreted to mean the future maintenance of population size and range at the levels present at the time of the directive. The findings of Watson & Wilson (2018) suggest that this directive was not being satisfied, at least in some of the areas that they studied. However, there is little reliable information on mountain hare range and population size on a national scale. Scottish Natural Heritage (SNH) commissioned an evaluation of methods for counting mountain hares. Based on counting in October and November and working on moorlands in Perthshire and the north-east of Scotland, Newey *et al.* (2018) used the capture-recapture method as a benchmark against which to judge the effectiveness of different methods. They also concluded that counting from one hour after sunset using either spotlight or thermal cameras gave the closest correlation with the capture-recapture benchmark, and that daylight

counting from one hour after sunrise gave inconsistent count data compared with night-time counts. This work will form the basis for systematic surveys of managed moorland in Scotland (R. Raynor, SNH, pers. comm.).

The Lammermuir Hills in south-east Scotland (55.8333° N, 2.7333° W) is an area largely managed for driven red grouse shooting. In 2014 it was reported that the RSPB had evidence for 1,500-1,700 mountain hares having been killed that year on several shooting estates in the Lammermuir Hills (Edwards, 2014). However, there were no estimates of population size against which to judge the impact of this cull number. Here we report the results of mountain hare counts at three Lammermuir locations around sunrise in spring between 2017 and 2019. In addition, a diel study used camera traps to investigate whether that time of day and time of year were associated with high levels of mountain hare activity.

MATERIALS AND METHODS

Counting routes and methods

We counted on three hills – Meikle Says Law (535 m), Lammer Law (527 m) and Newlands Hill (423 m) – in the north-west Lammermuir Hills. All are in red grouse shooting estates on which the heather moorland is managed by heather-burning and predator control. Mountain hares were counted along the survey routes shown in Fig. 1. The Meikle Says Law route is shown in detail in Fig. 2. The Lammer Law and Newlands hill routes were completed by a single group of observers within 3 h. Due to the length of time required for completing the Meikle Says Law route, counting was conducted by two groups following the solid line and broken line paths to meet at the summit.

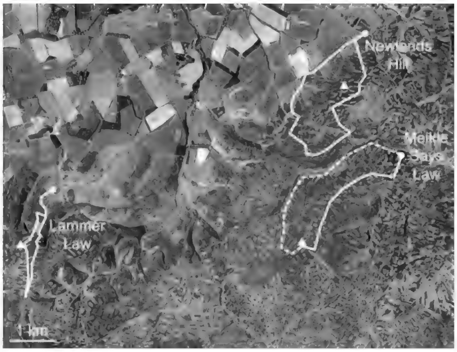

Fig. 1. The north-west Lammermuir Hills, Scotland and the three counting routes. The counting routes are shown as white lines. Due to the length of time required for completing the Meikle Says Law route, we counted in two groups following the solid line and broken line routes to meet at the summit. The white triangles indicate the summit of each hill. The white circles are the start of each transect. (Microsoft product screen shot reprinted with permission from Microsoft Corporation)

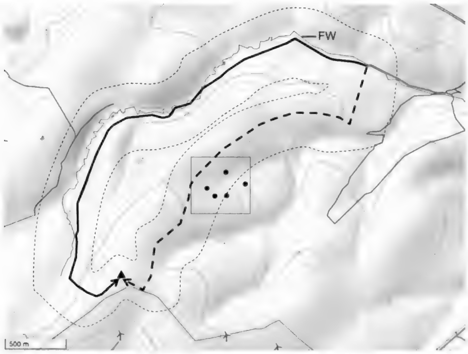

Fig. 2. The Meikle Says Law counting route, north-west Lammermuir Hills, Scotland, which was walked by two teams along two routes (solid and broken lines) between -1/+2 h around sunrise. The area over which mountain hares (*Lepus timidus*) can be counted with binoculars is indicated by grey broken lines on either side of the routes. The study area for collecting diel activity data is shown as a box of 0.5 x 0.5 km containing the positions of five trail cameras as black circles. The black triangle is the summit of Meikle Says Law at 535 m. FW, Faseny Water. The base map is from OpenTopoMap.org. Copyright is held by OpenStreetMap contributors. Copyright conditions are at https://www.openstreetmap.org/copyright.

The counting routes are composed of estate vehicle tracks, some smaller paths and a little rough heather walking. The routes were chosen to encompass broad views on both sides of the path with an emphasis on slopes rising upwards away from the observer. This is especially the case for the route along the valley of the Faseny Water (Fig. 2). The area that could be observed from the counting route was estimated using a map area calculator setting the detection distance with binoculars on either side of the route as either 300 m or 200 m depending on the sloping features of the terrain. This should be regarded as a rough estimate of area because of the subtleties in these slopes. The length of the counting route used in the encounter rate calculation was measured using a Garmin GPS device. It should be emphasised that this detection distance for binoculars is heavily dependent on the hares being active, on having their white winter coat, and also on good visibility. Surveys were only conducted in fair, clear, calm weather without snow on the ground. An important aspect of our counting method is that we are observing active hares, not flushing them from cover when they are resting.

Routes were followed consistently between survey dates using a Garmin GPS device. Counting was conducted continuously with small groups of 2-4 surveyors with binoculars. There was corroboration and consultation at a set of fixed stopping point and tight group walking between stopping points. Considerable care was taken to avoid double counting by keeping mental and written records of the location of hares seen and their direction of movement as the route was walked. Each of our counting routes has a region in the centre which is not surveyed. The advantage of this is that it reduces the risk of hare movement away from one survey team then

leading to counting by the second team (or on the return route in the case of transects that are walked as a single loop). Counting was started approximately 1 h before sunrise and was completed within 3 h. Mountain hares on each of the three hills were counted twice during the March-April period in each of the three years of the survey.

We are aware that our counting method does not follow the principles of random linear transects. We argue that, for the hill environment, the method we use is an appropriate one to maximise our ability to see hares at a distance. Our routes are followed precisely and repetitively and the review positions along the routes are constant. This is a valid method when our aim is to provide a record of changes in hare numbers at these locations over the years.

The routes were also followed starting 1 h after sunset and counting by means of a thermal camera (FLIR Scout II 640 thermal imaging camera). The effective range of the thermal equipment used was about 150-200 m.

Activity studies

Five camera traps (AUCEE Hunting Camera, 12MP 1080P Full HD Infrared Wildlife Camera with Night Vision) were placed on the eastern slopes of Meikle Says Law in positions of known hare activity such as browsing areas and gullies used as hare routes (Fig. 2). Camera traps were triggered by motion either in daylight or at night with a ten second delay between triggers. Time stamps were set to Greenwich Mean Time throughout the year.

For each image that contained a mountain hare an evaluation was made as to whether or not it represented an independent event ("hit"). This involved assessment of the timing, appearance, direction of movement and behaviour of hares in the preceding and following images. Images that were separated by less than one minute were discounted unless image evidence indicated that they were triggered by a different hare. Images separated by more than one minute were not recorded as independent events if image evaluation indicated that they were triggered by the same hare. The time stamps for hits were tabulated in Excel, categorised as morning (before 12:00) and afternoon (12:00 and after) and then re-calculated as decimal time relative to either sunset (afternoon group) or sunrise (morning group). Sunrise or sunset times were taken from data tables at https://www.thetimeandplace.info/uk/ for the local village of Gifford (55.9040° N, 2.7470° W).

Our surveys are contained within a 3 h time block starting 1 h before sunrise and so the camera detections (hits) were further subdivided into the block of -1/+2 h relative to sunrise and those in the remaining 21 h. The hit rate is the number of hits during a month within a 3 h time block.

Statistical analysis was performed in R (R Development Core Team, 2019) to determine whether the hit rate in the -1/+2 h time block differed from that for the remaining 21 h. For each of four independent cameras, the hits for the months of March and April were combined, subdivided into the time blocks of -1/+2 h and the remaining 21 h. The hit rates were calculated and analysed by the Welch Two Sample t-test (Fig. 3).

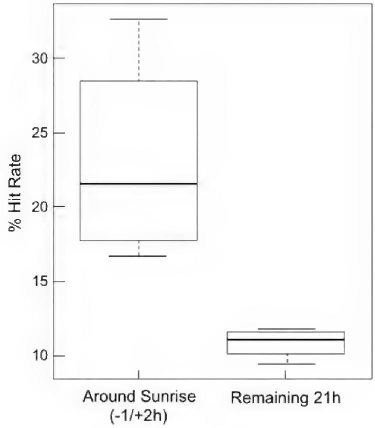

Fig. 3. Box and whisker plots for mountain hare (*Lepus timidus*) hit rates of -1/+2 h around sunrise and the remaining 21 h. The median percentage hit rate of each day division is shown as a horizontal bar, the box contains the 25-75% quartiles and the whiskers indicate the highest and lowest values. The "Remaining 21 h" column represents average percentage 3 h hit rates for that time block.

Statistical analysis was performed in R to determine whether the mean percentage frequency of hits in the 1/+2 h time block differed from that of the remaining 21 h. For each of four independent cameras, the hits for the months of March and April were combined and subdivided into the time blocks of 1/+2 h and the remaining 21 h. Analysis by the Welch Two Sample t-test gave t = 3.4, degrees of freedom = 3.1, and *P*-value = 0.04. The mean for the time block -1/+2 h around sunrise was 23.17% and the mean for the remaining 21 h was 10.98%.

RESULTS

Optimum time of year and time of day for counting

The data from Meikle Says Law obtained during 2015-2016 indicate that the maximum count of mountain hare via walked surveys with binoculars occurred in spring (March and April), with a higher count obtained when counting started 1 h before sunrise rather than 1 h after (Fig. 4).

Counting results for three hills over three years (2017-2019)

The mean number of mountain hare counted increased over the three years at Lammer Law and Newlands Hill (Fig. 5). For Meikle Says Law a similar trend was broken in September 2018 by a cull of 35 hares, which was associated with a lower number of hares in the 2019 counts (Fig. 5).

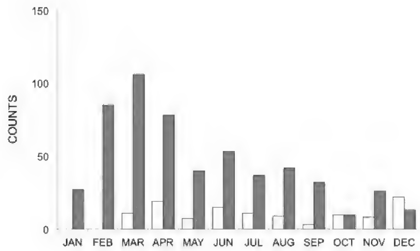

Fig. 4. Mountain hare (*Lepus timidus*) counts on Meikle Says Law, north-west Lammermuir Hills, Scotland. Effect of time of year and time of day. Clear bars show single counts starting 1 h after sunrise (2015). Grey bars show single counts starting 1 h before sunrise (2016).

Survey results expressed as encounter rate (hares seen per km) and as count density (hares seen per km^2)

The mean counts for 2019 were converted into a linear encounter rate and a count density in Table 1. The results of Table 1 show that Meikle Says Law is associated with the highest hare counts, but, when transect distance (encounter rate) or transect area (count density) is taken into account, all three hills are similar with values for count density of 23-33 hares per km^2.

Activity studies

The different patterns of hare activity captured by the camera traps in October and March are shown in Fig. 6. This is part of a larger data set, the whole of which is considered in a separate article dealing with changing annual diel patterns (Pettigrew, submitted). We focus on the activity in March (and April) here because the hare counts of Fig. 5 are obtained in March and April. October is chosen as the comparator month because it has a similar pattern of daylight/night hours (Fig. 6A) and also because the assessment of counting methods by Newey *et al.* (2018) was performed during October and November.

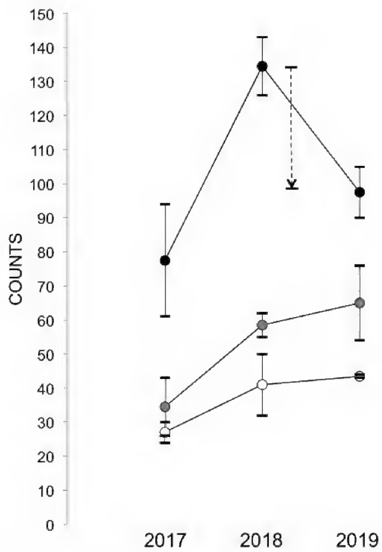

Fig. 5. Trends in annual counts of mountain hares (*Lepus timidus*), north-west Lammermuir Hills, Scotland. For the three years 2017-2019, the counts for Meikle Says Law are shown as black circles, Newlands Hill as grey circles and Lammer Law as open circles. The circles are the mean of the March and April counts and the limits of the bars are the two individual counts. The broken arrow for Meikle Says Law represents a cull of 35 hares carried out by the estate in September 2018.

				Moorland		Alpine	
	MSL	**LL**	**NH**	**ML (pre 1996)**	**ML (post 1996)**	**Cairnwell (pre 1988)**	**Cairnwell (post 1988)**
Count	98	44	65				
Transect length (km)	7.6	4.5	6.9				
Transect area (km^2)	4.17	1.32	2.5				
Encounter rate (hares per km)	12.9	9.8	9.4				
Density (hares per km^2)	23	33	26	33.8	2.0	15.1	63.3

Table 1. Density and encounter rates of mountain hares (*Lepus timidus*) on three hills in the north-west Lammermuir Hills, Scotland. The counts shown are the average between the April and the March count in 2019 from the data in Fig. 5. The transect area was estimated using a map area calculator setting the identification distance on either side of the route as either 300 m or 200 m depending on the terrain. The densities for Morven Lodge (ML) and Cairnwell are from Watson (2013.) MSL, Meikle Says Law; LL, Lammer Law; NH, Newlands Hill.

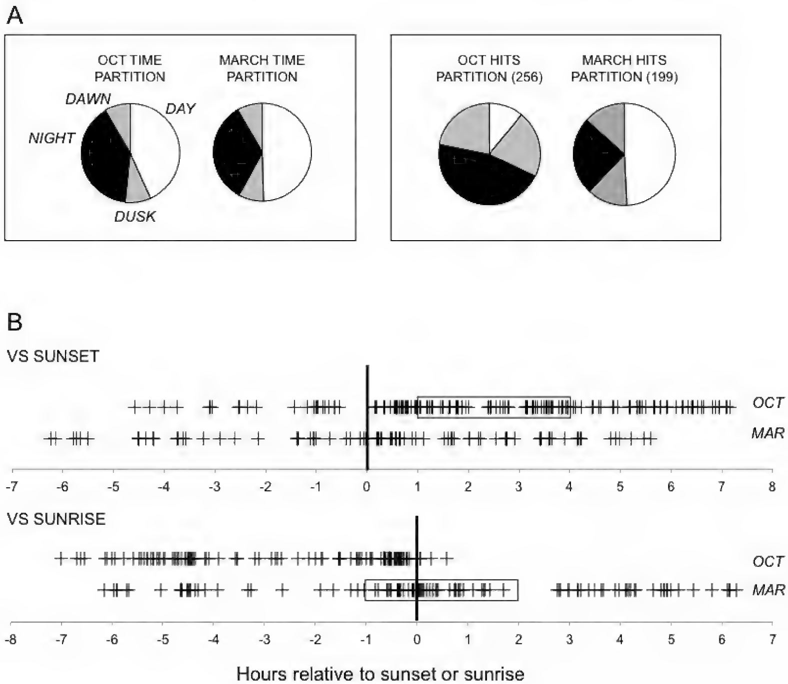

Fig. 6. Measurement of mountain hare (*Lepus timidus*) activity using camera traps for the months of October (2018) and March (2019). This is part of a larger data set considered in a separate article (Pettigrew, submitted). (A) In the time charts, the sectors represent the mean daylight hours (white), the mean night hours (black) and the 2 h each for dusk and dawn (grey). In the hits charts, the sectors represent the same day divisions but their size represents the number of hits on five cameras in that day division for that month with the total hits shown in each title. (B) Hits recorded by the camera traps were calculated as Greenwich Mean Time in decimal hours relative to sunset (top graph) or relative to sunrise (bottom graph) depending on whether they occurred in the second half of the day or the first half. The vertical bars represent sunset and sunrise. In each graph the top line of crosses shows the hit times for October and the bottom row of crosses the hit times for March. The boxes represent the time periods used for counting hares in this paper (March, -1/+2 h versus sunrise) and in the planned national census (October, +1/+4 h versus sunset).

In contrast to the time partition, the partition of camera hits between daylight and night is very different between the two months of October and March (Fig. 6A). October is associated with a much lower proportion of hits in daylight (Fig. 6A) and, in particular, in the daylight period between sunrise and noon (Fig. 6B).

Since surveys start 1 h before sunrise and take 2-3 h to complete, the raw data from Fig. 6 have been grouped into hits within this -1/+2 h time block and hits per 3 h blocks in the remaining 21 h. The latter are expressed as a percentage 3 h rate. A percentage rate of 12.5% for a three hour block would be obtained if all eight blocks in the 24 h cycle contained the same number of hits. The spring period of March and April is associated with percentage hit rates of 23-25% (Fig. 7A) and these are significantly higher than the rate associated with the remaining 21 h.

It should be noticed, however, that a high percentage rate of hits during the -1/+2 h period around sunrise is not sufficient in itself to justify that period as the time of choice for counting. Since a count takes 2-3 h to complete, it is important that hares are active during that whole period. As an example, although the -1/+2 h period relative to sunrise in October has a moderately high rate of hits of 16% (Fig. 7A), that activity is concentrated within the hour of dawn (Fig. 6B) and the second (and third) hour of that period is associated with almost no hare activity. This is in contrast to the -1/+2 h period relative to sunrise in March where the pattern of activity is spread over the three hours (Fig. 6B). Also the peak of activity in August and September in Fig. 7A would appear to offer an alternative counting time of year. However, mountain hares lose their white winter coat at the end of April and become much more difficult to spot even if they are active.

Spotlight counting in the study of Newey *et al.* (2018) which assessed different counting methods was performed during the period +1/+4 h after sunset in October and November. That timing is associated with high levels of hare activity (Fig. 6B) with 19-24% of hits (Fig. 7B).

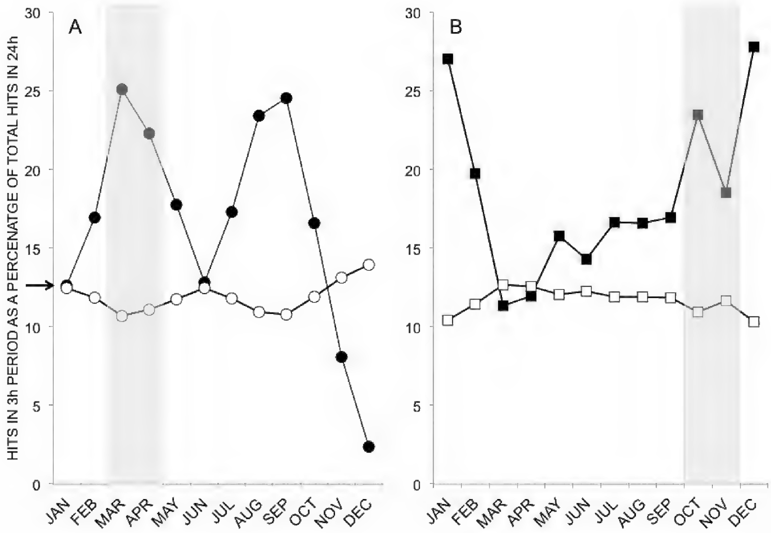

Fig. 7. The rate of mountain hare (*Lepus timidus*) camera hits in the 3 h time blocks associated with the counting performed in this paper and with the counting done in Newey *et al.* (2018). (A) The closed circles represent the percentage rate of camera hits during the 3 h period (-1/+2 h) around sunrise which is the survey period used in this paper. The open circles represent the average percentage 3 h rates for the remaining 21 h of the day. The arrow on the vertical axis represents the 12.5% per 3 h if all eight 3 h blocks in one day had the same rate of hits. The grey shaded area shows the two months used for counting in this paper. (B) The closed squares represent the rate of camera hits during the 3 h period of +1/+4 h after sunset. The open squares represent the average 3 h rates for the remaining 21 h of the day. The grey shaded area shows the two months used for counting in the study of Newey *et al.* (2018).

DISCUSSION

Counting method

The decision made to count mountain hare in March and April was based on their higher visibility at that time of year. During these months, their white winter coat (moulted towards the end of April in the Lammermuir Hills) is viewed against a non-white habitat (when clear of snow). Mountain hares are also more active (and therefore visible) in daylight hours than at other times of year (Angerbjörn & Flux, 1995). Our non-disturbance counting method with broad views of the habitat can give a less intrusive index of population size than a method which involves walking strict lines and flushing hares. Watson (2013) counted in early morning in spring with binoculars in the absence of snow cover and found that there was little or no difference between binocular counts and those performed by pointer dogs. He therefore considered that he was close to estimating total population size for his transects. Our methodology is similar to his.

In an assessment of counting methods, Newey *et al.* (2018) concluded that daylight counting was unreliable compared with the other methods. However, the daylight counting done by Newey *et al.* was conducted in October/November and started 1 h after sunrise, a timing that corresponds to low count numbers in this study (Fig. 4) and also corresponds to zero hare activity in our the camera trap hare activity study (Fig. 6B). Counting at this time gave a mean encounter rate of one hare per km (Newey *et al.*, 2018) (in contrast to 7.85 hares per km for counting with a thermal camera 1 h after sunset over the same areas). Almost all hares counted by Newey *et al.* (2018) during daylight counting were flushed from cover by human proximity.

The data presented here show that a very different situation applies during spring when counting started before sunrise. The activity studies with camera traps show that the period of -1/+2 h around sunrise coincides with high hare activity. The encounter rates (Table 1) are around ten hares per km on all three hills, at least as high as those counts obtained by Newey *et al.* (2018) using spotlight or thermal methods at night. The work described here indicates that daylight counting in spring (particularly if started in the dawn period) is a useful way to survey the mountain hare that may be less disruptive of the environment (and the hares themselves with their sensitive night vision) than a night-time method such as straight line walking with a spotlight.

Our activity profile for the hares in October and November shows a cluster of hits in the period of +1/+4 h after sunset (Fig. 6B) with a hit rate of 19-24% (Fig. 7B). These results support the choice of survey

timing during the night in October used by Newey *et al.* (2018).

Newey *et al.* (2018) found both spotlight and thermal camera surveys gave acceptable correlation with their benchmark method of capture/recapture. In our study, a thermal camera was used to perform spring and autumn counts starting at 1 h after sunset. This method yielded counts that were about half those obtained in sunrise counting in spring with binoculars. The range of our thermal camera may be as low as 150 m for reliable identification, roughly half the range of binoculars. Allowing for this, the thermal camera surveys in either spring or autumn yield count densities that are similar to those obtained around sunrise in spring using binoculars.

However, the thermal camera can be associated with difficulties in species identification. In one of our survey areas, Newlands hill, the ranges of brown hare (*Lepus europaeus*) and mountain hare overlap and the two cannot be reliably distinguished using the thermal camera. All of our transects contain rabbits (*Oryctolagus cuniculus*) which, although smaller and with a different running style, can also present species identification problems at a distance with the thermal camera.

Thus counting by thermal camera after dusk does not afford additional benefit compared with counting with binoculars in spring during and immediately after the dawn period.

Of the mountain hare survey methods tested by Newey *et al.* (2018), none, apart from the capture-recapture method, and the Distance sampling included in the Appendix of the report, enable calculation of a total population size. Therefore these methods, along with the method used in this paper should be seen as un-calibrated indices of population size, year-on-year.

There are two further considerations regarding counting methodologies for the mountain hare when applied on a national scale. Firstly, in the public perception, it may be preferable to have a counting procedure that is seen to be independent of the shooting estates – current plans for surveys of managed moorland involve the participation of gamekeepers (R. Raynor, SNH, pers. comm.). Secondly, compared with dawn counting with binoculars, the aspects of night walking on moorland is more challenging for volunteer groups and the cost of the equipment can be prohibitive.

Mountain hare counts

Our counts in three successive years on three hills in the Lammermuir Hills are consistent with generally stable and substantial populations. This is so even in the case of Meikle Says Law, where a limited cull took place in 2018. We were supplied with that culling information based on a relationship of trust between the Mayshiel Estate and the Lammermuir Hare Group. Having culling information will be an important component in judging the stability of the Lammermuir hare populations using future counts over the coming years.

Our count densities (Table 1) are broadly in the same range as those found in the Scottish highland areas of Morven Lodge (moorland) and the Cairnwell (alpine) by Watson (Watson, 2013; Watson & Wilson, 2018). The count densities reported in this paper will be subject to greater error because our calculation of surveyed area based on "reach" of binoculars has intrinsic imprecision compared with straight line counts. The results of Watson & Wilson (2018) for Morven Lodge show the striking decline in the population density index after 1996 that Watson found in other moorlands of north-east Scotland. As noted above, Watson & Wilson (2018) attribute these declines to mountain hare culling by estates, which is done in the belief that removal of mountain hares will limit the spread of the louping-ill virus.

The conservation of mountain hares is often portrayed as a simple issue of prevention of culling. In Sweden, the average winter survival for adult hares was 42% at low predation pressure but 19% at high predation (Angerbjörn & Flux, 1995). Therefore the annual morbidity on managed red grouse moors may be about half that in unmanaged habitats, and the main contributory factor to that is likely to be the control of ground and probably avian predators (although habitat management such as muirburn will contribute). As a consequence, in Scotland, mountain hare populations in such managed environments can increase to densities that can be as high as 245 hares km^{-2} whereas on unmanaged moorland, the numbers can be as low as 0.5-3 km^{-2} (Watson & Hewson, 1973).

With such high densities, culling is seen by the shooting estates as part of land management (a topic evaluated by Brooker *et al.* (2018)) with managers arguing that dense hare populations encourage the spread of disease. Relevant to that argument is the evidence of Newey & Thirgood (2004) who found high nematode burdens in Scottish mountain hares. When the females were treated with anthelmintics, they showed increased fecundity. One might speculate that a high nematode burden in a dense population could therefore lead to a population decline and that, in such circumstances, carefully managed culling might limit overpopulation and the spread of the parasites. However, evidence is needed for the effect of overpopulation on the spread of disease in mountain hares before culling can be justified.

One might argue that there are two distinct populations of mountain hares in Scotland that could be subject to different conservation criteria. Because the relict population on the high alpine habitats of the Central Highlands is the true native population, this could be regarded as the key conservation target and should receive priority. On the other hand, carefully licensed culling may be appropriate for dense populations that originate as transplants onto managed red grouse moors.

ACKNOWLEDGEMENTS

I would like to thank the three head keepers on the three survey Estates – Phil Savage (Mayshiel Estate), Ian Elliot (Hopes Estate) and John Fraser (Snawdon Estate) for their permission to survey and their helpful assistance. Robbie Douglas Miller (the owner of the Hopes Estate) coordinated regular meetings.

The Lammermuir Hare Group is composed of volunteers interested in the mountain hare. There are about 40 individuals in the larger group including visiting students from University courses.

I thank Colin Ballantyne, Angus Currie, Sarah Chambers, Dave Habgood, John Hardy, Joyce Kent, Graeme MacGregor, Maxine Pettigrew, Duncan Priddle, Gordon Steele and Peter Wells for invaluable help in performing the bulk of the survey work. Occasional help with the survey work was provided by students from Edinburgh Napier University and the University of Edinburgh.

The statistics in R were done under the guidance of Valentina Di Vita. Valentina Di Vita and Jason Gilchrist greatly improved the manuscript with helpful comments.

The camera traps and the thermal camera were purchased with generous funding by the People's Trust for Endangered species.

REFERENCES

Angerbjörn, A. & Flux, J.E.C. (1995). *Lepus timidus*. *Mammalian Species* 495, 1-11. https://doi.org/10.2307/3504302

Council of the European Union (1992). *Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora.*

Brooker, R., Hester, A., Newey, S. & Pakeman, R. (2018). *Socio-economic and Biodiversity Impacts of Driven Grouse Moors in Scotland. Part 2: Biodiversity Impacts of Driven Grouse Shooting in Scotland*. https://sefari.scot/research/socioeconomic-and-biodiversity-impacts-of-driven-grouse-moors-in-scotland

Edwards, R. (2014). Outrage over mountain hare 'massacre'. *The Herald*, 28th September.

Flux, J.E.C. (1970). Life history of the Mountain hare (*Lepus timidus scoticus*) in north-east Scotland. *Journal of Zoology* 161, 75-123. https://doi.org/10.1111/j.1469-7998.1970.tb02171.x

Gilbert, L. (2016). Louping-ill virus in the UK: a review of the hosts, transmission and ecological consequences of control. *Experimental and Applied Acarology* 68, 363–374. https://doi.org/10.1007/s10493-015-9952-x

Harrison, A., Newey, S., Gilbert, L., Haydon, D.T. & Thirgood, S.J. (2010). Culling wildlife hosts to control disease: mountain hares, red grouse and louping-ill virus. *Journal of Applied Ecology* 47, 926–930. https://doi.org/10.1111/j.1365-2664.2010.01834.x

Hewson, R. (1984). Mountain hare *Lepus timidus* bags and moor management. *Journal of Zoology* 204, 563-565. https://doi.org/10.1111/j.1469-7998.1984.tb02388.x

Jones, L., Gaunt, M., Hails, R., Laurenson, K., Hudson, P.J., Reid, H.W. & Gould, E. (1997). Amplification of louping-ill virus infection during co-feeding of ticks on mountain hares (*Lepus timidus*). *Medical and Veterinary Entomology* 11, 72–176. https://doi.org/10.1111/j.1365-2915.1997.tb00309.x

Laurenson, M.K., Norman, R.A., Gilbert, L., Reid, H.W. & Hudson, P.J. (2003). Identifying disease reservoirs in complex systems: mountain hares as reservoirs of ticks and louping-ill virus, pathogens of red grouse. *Journal of Animal Ecology* 72, 177–185. https://doi.org/10.1046/j.1365-2656.2003.00688.x

Newey, S. & Thirgood, S. (2004). Parasite-mediated reduction in fecundity of mountain hares. *Proceedings of the Royal Society B: Biological Sciences* 271 (Suppl. 6), S413–S415. https://doi.org/10.1098/rsbl.2004.0202

Newey, S., Fletcher, K., Potts, J. & Iason, G. (2018). Developing a counting methodology for mountain hares (*Lepus timidus*) in Scotland. *Scottish Natural Heritage Research Report No. 1022.*

Patton, V., Ewald, J.A., Smith, A.A., Newey, S., Iason, G.R., Thirgood, S.J. & Raynor, R. (2010). Distribution of mountain hares *Lepus timidus* in Scotland: results from a questionnaire. *Mammal Review* 40, 313-326. https://doi.org/10.1111/j.1365-2907.2010.00162.x

R Development Core Team (2019). *R - A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Reid, H.W. (1978). The epidemiology of louping-ill. In: Wild, J.K.H. (Editor). *Tick-borne Diseases and their Vectors*, pp. 501-507. Edinburgh University Press, Edinburgh.

Watson, A. (2013). *Mammals of the Northeast Highlands*. Paragon Publishing, Bath.

Watson, A. & Hewson, R. (1973). Population densities of mountain hares (*Lepus timidus*) on western Scottish and Irish moors and Scottish hills. *Journal of Zoology* 170,151-159. https://doi.org/10.1111/j.1469-7998.1973.tb01371.x

Watson, A. & Wilson, J.D. (2018). Seven decades of mountain hare counts show severe declines where high-yield recreational game bird hunting is practiced. *Journal of Applied Ecology* 55, 2663-2672. https://doi.org/10.1111/1365-2664.13235

The Glasgow Naturalist (2021) Volume 27, Part 3, 14-18 https://doi.org/10.37208/tgn27306

A review of rare Scottish pot beetles with information on surveys for six-spotted (*Cryptocephalus sexpunctatus*) and ten-spotted (*Cryptocephalus decemmaculatus*) pot beetles

S. Burgess

Buglife, Balallan House, 24 Allan Park, Stirling FK8 2QG

E-mail: suzanne.burgess@buglife.org.uk

ABSTRACT
Pot beetles (genus *Cryptocephalus*) are a fascinating group of beetles. Of the 19 species found in the U.K., 11 have been recorded in Scotland and seven of these have conservation designations. Buglife have successfully run public surveys in 2017, 2018 and 2019 for the six-spotted pot beetle (*Cryptocephalus sexpunctatus*) (Fig. 1) at Kirkconnell Flow, in Dumfries & Galloway and the ten-spotted pot beetle (*C. decemmaculatus*) (Fig. 2) at Black Wood of Rannoch in Perthshire. At Kirkconnell Flow, the six-spotted pot beetles were rediscovered during the first year of the survey in extremely low numbers, with a new colony found in the north of the site in 2019. At Black Wood of Rannoch, the ten-spotted pot beetle has now been recorded at three adjacent 1 km squares within the Camghouran area.

INTRODUCTION
Pot beetles are in the subfamily Cryptocephalinae (Order Coleoptera: Family Chrysomelidae). There are 19 species of pot beetle in the U.K. (Table 1), with the violet pot beetle (*Cryptocephalus violaceus*) recently being described as extinct and no longer on the U.K. species list (Hubble, 2014). At least 11 species are thought to occur in Scotland. Six of these have recent records on the National Biodiversity Network (NBN) Atlas and five have historic records that pre-date 1979 (Table 1).

Many species of pot beetle have suffered a decline in their distribution across the U.K. and are now quite rare. Six species are described as "Endangered" and two as "Vulnerable" in the most recent status review by Hubble (2014) (Table 1). Additionally, nine species are described as Nationally Rare and five as Nationally Scarce within Great Britain (Table 1). In Scotland, both the six-spotted pot beetle and the ten-spotted pot beetle are listed as a priority on the Scottish Biodiversity List (Table 1).

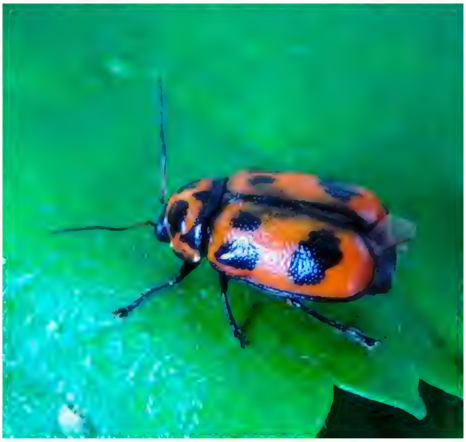

Fig. 1. Six-spotted pot beetle (*Cryptocephalus sexpunctatus*) at Kirkconnell Flow, Dumfries & Galloway, Scotland. Length *ca.* 5 mm. (Photo: S. Burgess)

Fig. 2. Ten-spotted pot beetle (*Cryptocephalus decemmaculatus*) at Black Wood of Rannoch, Perthshire, Scotland. Length *ca.* 4 mm. (Photo: S. Burgess)

Scientific Name	English Name	Notes
Cryptocephalus aureolus (Suffrian, 1847)		Historic records and a more recent record from 2015 in South Ayrshire. Rarity status: None, widespread across U.K.
Cryptocephalus biguttatus (Scopoli, 1763)		Rarity status: VU, NR
Cryptocephalus bilineatus (Linnaeus, 1767)		Rarity status: LC, NS
Cryptocephalus bipunctatus (Linnaeus, 1767)	Two-spotted pot beetle	Historic records for this species from across Scotland. Recorded at Kirkconnell Flow, Dumfries and Galloway, SSSI in June 2017. Rarity status: LC, NS.
Cryptocephalus coryli (Linnaeus, 1767)	Hazel pot beetle	One record from Kincraig, Highland, from 1946. No recent records. Rarity status: EN, NR
Cryptocephalus decemmaculatus (Linnaeus, 1767)	Ten-spotted pot beetle	Recorded in Scotland at Black Wood of Loch Rannoch, Perthshire, one site in England. Rarity status: EN, NR, SBL
Cryptocephalus exiguus (Schneider, 1792)	Pashford pot beetle	Rarity status: CR (PE), NR
Cryptocephalus frontalis (Marsham, 1802)		Rarity status: NT, NR
Cryptocephalus fulvus (Goeze, 1777)		Not recorded from Scotland. Rarity status: None, widespread in England and Wales.
Cryptocephalus hypochaeridis (Linnaeus, 1758)		Rarity status: LC, NS
Cryptocephalus labiatus (Linnaeus, 1761)	Black birch pot beetle	Recorded at several sites across Scotland. Rarity status: None, widespread across the U.K.
Cryptocephalus moraei (Linnaeus, 1758)		Pre-1979 record for site in North Ayrshire. No recent records in Scotland. Rarity status: None, widespread in England and Wales
Cryptocephalus nitidulus (Fabricius, 1787)	Shining pot beetle	Rarity status: EN, NR
Cryptocephalus parvulus (Müller, 1776)		At least two old records from pre-1979 in Scotland. Rarity status: LC, NS.
Cryptocephalus primarius (Harold, 1872)	Rock-rose pot beetle	Records from Scotland from pre 1900s and none shown on NBN Atlas. Rarity status: EN, NR.
Cryptocephalus punctiger (Paykull, 1799)	Blue pepper-pot beetle	At least two old records from pre-1979 in Scotland. No recent records in Scotland. Rarity status: VU, NR
Cryptocephalus pusillus (Fabricius, 1777)		Recorded in Scotland in Dumfriesshire and Highlands. Rarity status: None, widespread across England and Wales.
Cryptocephalus quercetin (Suffrian, 1848)		Rarity status: EN, NR
Cryptocephalus sexpunctatus (Linnaeus, 1758)	Six-spotted pot beetle	Recorded in Scotland from Kirkconnell Flow NNR. Rarity status: EN, NR, SBL

Table 1. List of *Cryptocephalus* pot beetles recorded in the U.K., with notes on when the species was described and those recorded in Scotland. Records taken from NBN Atlas and Cox (2007). Notes also include reference to rarity designations for each species as described by Natural England (Hubble, 2014) including (1) IUCN threat categories: CR (PE), Critically Endangered (Possibly Extinct); EN, Endangered; VU, Vulnerable; NT Near Threatened and Least Concern: LC; (2) Great Britain rarity: NR, Nationally Rare; NS, Nationally Scarce; and (3) whether the species is on the Scottish Biodiversity List: SBL. Scientific names in bold highlight species with records (either historic or more recent) from Scotland.

Pot beetles get their English name from the protective shell-like cocoon or "pot" that the larvae inhabit. The pots are initially built by the female during and immediately after egg laying, with the egg being held between the rear metatarsi and covered by the female's faeces. Once covered, the pots are dropped to the ground amongst leaf litter and this forms much of the larval diet. The structure of the pot varies between the different species of pot beetle. When the egg hatches, the larva makes a hole at one end of the pot allowing it to feed and move around in the leaf litter. As the larva grows, the pot needs to be enlarged which it does using its own faeces. The larvae can take up to two years to develop into adults (Hubble, 2017).

Another key feature of this group is that the head of the adults is hidden under their bulging pronotum and is the source of the scientific name for the genus *Cryptocephalus*, which means "hidden head".

Similar to many of their leaf beetle relatives, adult pot beetles are typically found feeding on the leaves of their host plant and if disturbed feign death (thanatosis) and drop to the ground.

SIX-SPOTTED POT BEETLE

The six-spotted pot beetle (*C. sexpunctatus*) (Fig. 1) was once widespread in southern England with scattered records as far north as Ayrshire in Scotland (Piper, 2002; Anon., 2010; C. Barnes, pers. comm.). The current status of the beetle is that it now has an extremely localised distribution in the U.K. with recent records in Scotland from Kirkconnell Flow, Dumfries & Galloway, and most recently in May 2020 from two new areas in Dumfries & Galloway near Kirkton (NX972820) and at Racks Moss (NY03247407). The beetle has been recorded at two sites in England, at Stockbridge Down in Hampshire and a recent discovery of a population in Lincolnshire at Stockbridge Down, despite repeated searches, only a few individuals have been recorded since 1990.

The six-spotted pot beetle has a reddish-yellow thorax and elytra with usually three black spots (sometimes four) on each elytral wing case (Fig. 1). Adult beetles are 4.5-6.5 mm in length (Hubble, 2012). This species has been recorded feeding on leaves of the saplings of aspen (*Populus tremula*), crack willow (*Salix fragilis*), hawthorn (*Crataegus monogyna*), oak (*Quercus* spp.) and birch (*Betula* spp.). Adults have also been recorded on the flowers of wood spurge (*Euphorbia amygdaloides*) and yellow Asteraceae species (Cox, 2007).

TEN-SPOTTED POT BEETLE

Only two sites are currently known to support ten-spotted pot beetles (*C. decemmaculatus*) in the U.K. - Wybunbury Moss National Nature Reserve (NNR) in Cheshire, and Camghouran on the south side of Loch Rannoch within the Black Wood of Rannoch in Perthshire (Piper & Compton, 2013; Piper, 2013, 2015). Single specimens have previously been recorded from two other sites in Scotland, both in Aberdeenshire: one at Muir of Dinnet (designated as a National Nature Reserve (NNR), Special Area of Conservation (SAC) and Site of Special Scientific Interest (SSSI)) in 1986; and the other within Morrone Birkwood Nature Reserve (also designated as a NNR, SAC and SSSI) in Braemar in 1959. However, the exact locations within both sites is unknown (Littlewood & Stockan, 2013).

The ten-spotted pot beetle (Fig. 2) has five black spots on each yellow-orange elytron and a black pronotum with a distinctive central yellow mark (Cox, 2007; Hubble, 2012). The markings of this species are highly variable, displaying a range of spot sizes. Melanic forms, known as subspecies *C. decemmaculatus bothnicus,* with completely black elytra but retaining the yellow mark on the pronotum, have been widely recorded in the U.K. (Piper, 2002); around 30% of both male and female individuals found at Camghouran at Loch Rannoch in 2017 displayed this colour form (Burgess & Shanks, 2017).

Females of this species have relatively shorter prothoracic limbs and antennae than males and are often slightly bulkier reaching 4 mm in length, whereas males generally reach 3 mm (Hubble, 2012).

The ten-spotted pot beetle feeds on the leaves of willow (*Salix* spp.) growing in sheltered *Sphagnum*-covered heathland habitat on hillsides on the edges of quaking bogs. Favoured host plants in Scotland appear to be small specimens (under 2 m tall) of eared willow (*Salix aurita*) but they have been recorded in England from grey willow (*S. cinerea*), goat willow (*S. caprea*), and occasionally downy birch (*Betula pubescens*) (Cox, 2007).

POT BEETLE SURVEYS

Background

Buglife ran surveys for the six-spotted and ten-spotted pot beetles during early summer in 2017, 2018 and 2019 (Table 2). The surveys were advertised to members of the public and during the day attendees were provided with training on:

(1) how to survey for invertebrates (with a focus on pot beetles and their leaf beetle relatives) using sweep nets and through direct observation;
(2) how to identify invertebrates observed and collected through sweep nets and pots;
(3) the importance of monitoring sites;
(4) the importance of the habitats at the site being surveyed for invertebrates and other wildlife; and
(5) how to record invertebrates.

Each attendee was provided with a sweep net and pots. Attendees were also shown the target plant for the pot beetle species (see below for more information on host plants for each pot beetle species surveyed), and to focus attention on surveying saplings of these tree species that were less than 2 m in height.

Year	Kirkconnell Flow six-spotted pot beetle	Black Wood of Rannoch ten-spotted pot beetle
2017	23rd, 24th June 2017	1st July 2017
2018	22nd, 23rd June 2018	7th, 8th July 2018
2019	21st, 22nd June 2019	3rd, 4th July 2019

Table 2. Dates on which Kirkconnell Flow, Dumfries & Galloway and Black Wood of Rannoch, Perthshire, both Scotland, were visited in 2017, 2018 and 2019 to survey for pot beetles.

Survey at Kirkconnell Flow

Located 6 km south of Dumfries, Dumfries & Galloway, Kirkconnell Flow is a raised bog that lies on the flood plain of the River Nith and is designated as a SSSI and SAC. Permission to run the surveys and collect invertebrates with members of the public was granted by Scottish Natural Heritage (SNH) who own and manage this Nature Reserve. Areas surveyed within this site for the beetle each year focused on small trees found along the edges of the footpath that leads from the car park into the raised bog, as well as on small trees along the edge of the bog itself and found elsewhere on the site.

In 2017 two adults of the six-spotted pot beetle were recorded along the main footpath leading to the raised bog from the car park at grid reference NX96437020. These were the first two individuals of this species to have been recorded in Scotland since the late 1990s (Burgess & Shanks, 2017). In 2018 the area was revisited with volunteers to look for the beetles in new areas of the Nature Reserve with an aim to determine the health of the population. No species of pot beetles were recorded that year (Lemon & Shanks, 2019). As only two adults of this species were recorded during the first two years of the project it was important to revisit Kirkconnell Flow in 2019. During two survey days in 2019 (Table 2), a total of 17 adult six-spotted pot beetles was recorded at Kirkconnell Flow; two individuals were found along the main footpath at separate locations at grid reference NX96297017 and NX96357020, and a further 15 adults were recorded at NX96337048; this area was identified by SNH staff as potentially having habitat that would support a population of the beetles and is a new area identified for the species (Burgess & Lindsay, 2019).

During the surveys it was observed that adults of the six-spotted pot beetle appear to favour the saplings of silver birch (*Betula pendula*) which are plentiful along the edges of the main footpath and raised bog at Kirkconnell Flow and within the open area discovered in 2019 (Burgess & Lindsay, 2019). Only adults were recorded during the surveys and only from silver birch, although there are saplings available of other tree species.

Two other species of pot beetle were recorded at Kirkconnell Flow during the surveys, the common black birch pot beetle (*C. labiatus*) (in 2017 and 2019) and two adults of the Nationally Scarce in Great Britain two-spotted pot beetle (*C. bipunctatus*) (in 2017 only) (Burgess & Shanks, 2017; Burgess & Lindsay, 2019).

Survey at Black Wood of Rannoch

The Black Wood of Rannoch is an area of ancient woodland growing along the south shore of Loch Rannoch in Perthshire, the area is designated as a SSSI and SAC. The ten-spotted pot beetles have previously been recorded within the Camghouran area at Black Wood of Rannoch and this area was the focus during each survey to determine the distribution and health of the population. Permission to run the surveys and collect invertebrates with volunteers was granted by the landowners through SNH.

During the first survey in 2017 (Table 2), effort was focused on surveying the last place the beetles had been recorded at grid reference NN544557. In this area, several adults were observed in a clearing approximately 6 m^2 in area (Burgess & Shanks, 2017). In 2018 this area was revisited (Table 2) and several adults were found within three separate areas of grid reference NN545557 (Lemon & Shanks, 2019). Several adults were then discovered in three areas of a new 1 km square at NN542566 (Lemon & Shanks, 2019). In 2019 the new area where beetles were discovered in 2018 (at NN542566) was visited and over 40 adults were counted (Burgess & Lindsay, 2019). A new 1 km square was visited in 2019 at NN5356 and a handful of adults was counted within two areas at NN53835681 and NN53345698 (Burgess & Lindsay, 2019). In view of the terrain it is very possible that the ten-spotted pot beetles are found across a wider area of the Black Wood of Rannoch. It was noted that they appear to favour saplings of eared willow that is less than 1.5 m in height and in open areas. The largest population observed within grid reference NN542566 appear to be doing well; this could be because the area is a wayleave for electricity pylons that is cleared every several years allowing for eared willow to regenerate, and so providing young saplings for the beetles to feed from.

Two species of pot beetle were recorded during the surveys at Black Wood of Rannoch, the common black birch pot beetle and *Clytra quadripunctata* (not strictly a pot beetle but included within the pot beetle subfamily), which is associated with the nests of wood ants (*Formica* spp.) and appears to be a new record for the area (Burgess & Lindsay, 2019).

CONCLUSION

Both the six-spotted and ten-spotted pot beetles are described as "Endangered" in the most recent International Union for Conservation of Nature (IUCN) status review (Hubble, 2014) and both are listed as a priority on the Scottish Biodiversity List. Both species are currently only known from one site each in Scotland, although they do have historical records that are worth investigating in future surveys. These surveys have

successfully found both target species with the help of volunteers and have recorded other species of invertebrates at both sites. Reports have been produced each year that have provided information on the surveys and recommendations on habitat management if needed, and future surveys to ensure the long-term survival of both species in Scotland. These reports are available on the Buglife website: www.buglife.org.uk.

ACKNOWLEDGEMENTS

Buglife would like to thank Scottish Natural Heritage for providing funding to allow surveys for both species that have helped rediscover these very rare species in Scotland. We would also like to thank all the volunteers who have participated in the surveys.

REFERENCES

Anon. (2010). *UK Priority Species Pages. Version 2: Six-spotted Pot Beetle* Cryptocephalus sexpunctatus. Joint Nature Conservation Committee, Peterborough. http://jncc.defra.gov.uk/_speciespages/251.pdf Accessed 15th April 2020.

Burgess, S. & Lindsay, J. (2019). *Spotting Pot Beetles: Survey Report and Habitat Recommendations*. Buglife. https://cdn.buglife.org.uk/2019/11/Spotting-pot-beetle-survey-report-2019-final.pdf Accessed 15th April 2020.

Burgess, S. & Shanks, S. (2017). *Spotting Pot Beetles: Survey Report and Habitat Recommendations*. Buglife. https://cdn.buglife.org.uk/2019/07/Spotting-pot-beetle-survey-report-final_0.pdf Accessed 15th April 2020.

Cox, M.L. (2007). *Atlas of the Seed and Leaf Beetles of Great Britain and Ireland*. Pisces Publications, Newbury.

Hubble, D. (2012). *Key to the Adults of Seed and Leaf Beetles of Britain and Ireland*. Field Studies Council, Shrewsbury.

Hubble, D. (2014). *A Review of the Scarce and Threatened Beetles of Great Britain: the Leaf Beetles and their Allies, Chrysomelidae, Megalopodidae and Orsodacnidae*. Natural England Species Status No. 19. http://publications.naturalengland.org.uk/file/6244884977549312 Accessed 15th April 2020.

Hubble, D. (2017). *Leaf Beetles*. Naturalists' Handbooks No. 34. Pelagic Publishing, Exeter.

Lemon, A. & Shanks, S. (2019). *Spotting Pot Beetles: Survey Report and Habitat Recommendations*. Buglife. https://cdn.buglife.org.uk/2019/07/Spotting-pot-beetle-survey-report-2018-final.pdf Accessed 15th April 2020.

Littlewood, N.A. & Stockan, J.A. (2013). *Surveillance of Priority Terrestrial Invertebrates in Scotland*. Scottish Natural Heritage Commissioned Report No. 609.

Piper, R.W. (2002). *Conservation Biology of* Cryptocephalus *Species and Other Threatened UK Beetles*. Ph.D. thesis, University of Leeds. www.rosspiper.net/wp-content/uploads/2013/05/Ross-Piper-PhD-thesis-2002.pdf Accessed 15th April 2020.

Piper, R.W. (2013). Cryptocephalus decemmaculatus *at Wybunbury Moss, Cheshire*. Natural England Research Reports.

Piper, R.W. (2015) Cryptocephalus decemmaculatus *at Wybunbury Moss, Cheshire*. Natural England Research Reports.

Piper, R.W. & Compton, S.G. (2013). How limited is dispersal in the rare beetle, *Cryptocephalus decemmaculatus* (Chrysomelidae, Cryptocephalinae)? *Journal of Insect Conservation* 17, 1229-1235. https://doi.org/10.1007/s10841-013-9604-6

The Glasgow Naturalist (2021) Volume 27, Part 3, 19-27 https://doi.org/10.37208/tgn27316

Low levels of faecal cortisol in bank voles (*Myodes glareolus*) in response to live-trapping

A. Acsai[1*], T. Drexler[1*], N.P. Evans[2] & D.J. McCafferty[3]

[1]Institute of Biodiversity, Animal Health & Comparative Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow, Graham Kerr Building, Glasgow G12 8QQ

[2]Institute of Biodiversity, Animal Health & Comparative Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow, Jarrett Building, Glasgow G61 1QH

[3]Scottish Centre for Ecology and the Natural Environment, Institute of Biodiversity, Animal Health & Comparative Medicine, College of Medical, Veterinary and Life Sciences, University of Glasgow, Rowardennan G63 0AW

[*]These two authors contributed equally to the study.

E-mail: dretom93@gmail.com (T. Drexler)

ABSTRACT

Small mammal trapping is a commonly taught field technique in ecology and population biology. However, there are still open questions regarding the extent to which trapping affects the welfare of small animals. This study investigated faecal cortisol as a non-invasive measurement of the physiological stress response of bank voles (*Myodes glareolus*) to live-trapping. Faecal cortisol concentrations were similar between samples collected from trapped and non-trapped voles, but were negatively correlated with capture duration. This result may suggest that any physiological stress response was short-lasting and the animals habituated to the trap. As such, effects on faecal cortisol were not apparent as mean faecal cortisol concentration was determined from multiple collected faeces. Future work should focus on characterising the potential stress response to trapping with greater temporal resolution.

INTRODUCTION

Live-trapping is widely used as a basic method in ecology and population biology to study the species composition of animal communities (Pearson & Ruggiero, 2003), for virological testing (Mills *et al*., 1995), and to estimate the density or range of a given species (Stickel, 1954; Wilson & Anderson, 1985). This technique is also commonly used in animal relocation or translocation programmes, either in conservation biology (Teixeira *et al*., 2007), or where animals are considered as pests or invasive species (Bertolino & Genovesi, 2003; Rosatte & MacInnes, 1989).

It is important to understand how specific features of live-trapping affect animal welfare. Such features include type of the trap used, the timing of setting the traps and how long animals are held captive. Choosing the appropriate measurements to assess the potential impacts of live-trapping, however, is challenging. One of the most commonly used methods to assess the effect of trapping on small mammals is to record changes in body mass when repeated captures occur over consecutive days (e.g. Pavone & Boonstra, 1985; Korn, 1987; Kaufman & Kaufman, 1994; Lindner & Fuelling, 2002; Pearson *et al*., 2003; Suazo & Delong, 2007). Such studies have shown that being held within a live trap can cause significant body mass loss and that decreases in body mass are correlated with trap mortality and reduced survival (Pearson *et al.* 2003). It is important to note that, where live-trapping occurs over a prolonged period of time and if animals are trapped repeatedly, even small daily mass losses can be cumulative (Korn, 1987). In this respect, small rodents can be the most sensitive animals to effects of live-trapping, as they have a low body mass and high metabolism (Pearson, 1947; Nagy *et al*., 1999).

Another important method for assessing the impact of live-trapping, is the measurement of physiological stress (e.g. Kenagy & Place, 2000; Koprowski, 2002; Fletcher & Boonstra, 2006; Mellish, 2010; Bosson *et al*., 2012). Trapping is a known stressor that activates the body's stress responses including the hypothalamo-pituitary-adrenal (HPA) axis (Ortiz & Worthy, 2000; Boonstra *et al*., 2001; Reeder *et al*., 2004). Activation of the HPA axis results in release of glucocorticoids (corticosterone/cortisol), which circulate within the blood and trigger a series of acute compensatory physiological adaptations that help the animal adapt to the stressor (e.g. increased circulating glucose levels which enhanced the capacity to flee from a stressor; National Research Council, 2008). It has been shown in meadow voles (*Microtus pennsylvanicus*) that plasma corticosterone concentrations are higher in animals captured in live traps as opposed to animals that are snap-trapped (Fletcher & Boonstra, 2006). Harper & Austad (2001) reported a positive relationship between the duration deer mice (*Peromyscus maniculatus*) are held captive in a live trap and glucocorticoid levels, but

not in red-backed voles (*Clethrionomys gapperi*). Bosson *et al.* (2012) showed that in North American red squirrels (*Tamiasciurus hudsonicus*), cortisol concentrations were related to the duration of capture, and different trap models induced different physiological responses. In the light of these studies there is a need to determine an appropriate checking interval for studies of small mammals, as it is clear that trapping causes stress, but the effects of trapping duration can be different for different species. It has also been shown that successive stressors (e.g. prolonged captivity, noise pollution) can have additive or cumulative effects (Moberg & Mench, 2000; Teixeira *et al.*, 2007) on a variety of body systems, affect cognitive abilities (McEwen & Sapolsky, 1995; Mendl, 1999) and result in negative impacts on health and survival (Wey *et al*., 2015).

For investigation of an acute physiological stress response, glucocorticoid concentrations in blood or saliva samples are often used, but where more chronic measures are required it is also possible to measure glucocorticoids in samples of urine, faeces and hair (Abelson *et al*., 2005). When assessing the physiological response to a stressor it is important to note that the sample collection methods can themselves be stressful (National Research Council, 2008), and have the potential to confound the results of the assessment. This particularly applies to the collection of invasive samples such as blood and saliva for the measurement of acute stress. Laboratory studies on the domestic rat (*Rattus norvegicus*) suggest that glucocorticoid concentrations are elevated within three to five minutes following the initiation of a stressor such as handling (Dallman & Bhatnagar, 2001). Similarly, it has been reported that in free-living vertebrates, blood samples must be collected within two minutes of capture to prevent any bias due to the effect of handling on glucocorticoid concentrations (Romero & Reed, 2005).

Assessing glucocorticoids using faecal samples is a non-invasive way to examine stress in both free living and live-trapped individuals (National Research Council, 2008). An important benefit of faecal samples and the subsequent analysis of faecal glucocorticoids is that, unlike blood samples, which provide an instantaneous snapshot of glucocorticoid levels at a precise moment in time, faecal glucocorticoid concentrations provide an integrated measure of circulating glucocorticoids over a period of time. This time frame is influenced by the gut transit time of that species (Palme *et al.*, 1996; von der Ohe & Servheen, 2002), which is short in the case of small mammals (Clemens & Stevens, 1980). Corticosterone metabolites can be detected in the faeces of red-backed voles for up to eight hours after a corticosteroid injection (Harper & Austad, 2000). Similarly, corticosterone metabolites can be detected in Syrian hamster (*Mesocricetus auratus*) faeces after four hours (Chelini *et al*., 2010), and in mice (*Mus musculus)* two hours after ACTH injection (Touma *et al*., 2004). Faecal corticosterone metabolites can also be detected two hours after trap confinement in North American deer mice (Eleftheriou *et al.*, 2020). However, these studies did not investigate time points shorter than four and two hours respectively and therefore it is possible that corticosterone metabolites occur in the faeces even earlier. In live traps, given that small mammals may feed and gut transit time can be as little as 0.8 h (Brandt's vole, *Microtus brandtii*: Pei *et al*., 2001), there is the possibility of assessing the corticosteroid concentrations in faeces while the animals are captive.

The aim of this project was to assess how trapping with standard methods commonly used in ecological studies influences the physiological stress response of a small rodent species. We examined if capture itself leads to elevated cortisol concentrations in trapped animals compared with non-trapped individuals, and if cortisol concentrations in both males and females were proportional to the time spent in the traps. Faecal cortisol metabolites have been already validated and used in more rodent species for stress assessment (e.g. Bosson *et al.*, 2009; Dantzer *et al.*, 2010; Montiglio *et al.*, 2012). We predicted that capture would increase faecal cortisol, and that faecal cortisol concentrations would be positively correlated with time spent in the trap (trap duration). We expected this relationship to be linear, or linear after a short delay associated with defaecation patterns. We chose the bank vole (*Myodes glareolus*) as a model species, because it is often used as a model species in ecological and evolutionary research. In addition, it occurs at relatively high densities and has a favourable conservation status (IUCN, 2016). The results of the study, however, have a wider relevance as they provide insight into how capture-induced stress in small rodents can be reduced.

MATERIALS AND METHODS

Study site

The study was conducted in an oak forest in Loch Lomond and the Trossachs National Park, Scotland in the vicinity of the Scottish Centre for Ecology and the Natural Environment (SCENE), University of Glasgow (56.129836 °N, 4.615282 °W) from 4th to7th June 2018.

Sample collection from non-trapped individuals

To collect samples for estimation of cortisol concentrations of non-trapped voles, we left 16 Ugglan traps (Grahnab AB, Sweden) overnight at the study site. This is a live-capture trap with an opening that lets only small rodents enter. The closing mechanism is based on a counter-weighted tilting door and allows the capture of multiple animals at the same time. This trap was chosen for our study because it is widely used in small-mammal studies and was reported to have higher efficiency and lower trap-induced mortality compared with Sherman traps (Jung, 2016). The doors of the traps were left open so that the animals could feed and defecate inside them without being caught. The use of the traps in this regard controls for any stress effect of the trap itself as opposed to a period of captivity within the trap.

Porridge oats mixed with peanut butter was placed inside the traps as bait, and a piece of apple as a water

source. Bedding material was provided for insulation. The traps were placed on the ground in three transects in three different areas in the forest at *ca.* 5 m spacing, oriented towards a runway or burrow in the leaf-litter. Faeces found in each trap were collected into 2 ml Eppendorf tubes and placed in a -20°C freezer within half an hour after collection until cortisol analysis. Faeces belonging to bank voles were selected, based on their morphology as identified using MacDonald & Barrett (1993). The droppings of this species are rounded, 0.8 cm long × 0.4 cm wide, and therefore can be distinguished from droppings of wood mouse (*Apodemus sylvaticus*) and yellow-necked mouse (*A. flavicollis*) by their smaller size. In contrast to the faeces of the field vole (*Microtus agrestis*), which is green and oval, those of the bank vole are brown to black. Traps were cleaned with soap and water before and after the first trapping session.

Live-trapping

The 16 Ugglan multi-capture traps were baited as before and placed in the previously used locations, but this time were set to catch animals. A DS1920-F5 temperature logger ibutton™ (Maxim Integrated, U.S.) was fixed to the back door of the trap with Velcro adhesive tape. The loggers were programmed to record temperature with 0.5°C precision every five minutes to detect body heat. Traps were set at 6:00 and were checked every day at 10:00, 14:00, 18:00 and 22:00, meaning that the maximal time an animal could spend in a trap was four hours. On one occasion an overnight (22:00-4:00) live-trapping session was conducted but, as the trapping success was no greater than during the day, this was not repeated. Live-trapping was conducted for a total of 46 hours. At each trap check, traps were cleaned and new bait and bedding placed into them.

In the case of a capture, the animal was transferred into a plastic bag and weighed with a Pesola spring balance ± 0.5 g. Sex was determined from the length of the urogenital gap, which is greater in males than in females. Animals were then released at the site of capture and the traps were repositioned to reduce the chance of recapture. The time of release was noted to allow the duration of capture to be calculated. All droppings from within each trap were collected into an Eppendorf tube (one tube for each capture) and stored as described previously for subsequent analysis. All double captures (i.e. two different animals entered the same trap in the same trapping session) were not included in the further analysis.

Estimation of the time spent in the traps

The time at which the animal entered the trap and the duration of captivity were determined by analysis of the logged temperature data and the known time of release. Temperature data were plotted in Microsoft Excel (version 2010) from the time of the previous trap check to the time of release. Trap entry was estimated based on a method described by Weidinger (2006), which detected predation of songbird nest boxes by reporting the time of a permanent decline in nest temperature. In our case the time point of a 1°C increase within five minutes, followed by a permanently elevated temperature, was defined to be the time of capture (Fig. 1).

Stress assessment – ELISA cortisol assay

Faecal cortisol was measured, following solvent extraction, using a commercially available ELISA (Cayman chemical Cortisol ELISA kit). This assay has a 100% cross reactivity with cortisol, <5% cross reactivity with prednisolone, <2% cross reactivity with cortexolone and <0.3% cross reactivity with 17-hydroxyprogesterone, cortisol glucuronide, corticosterone, cortisone, androstenedione, enterolactone, estrone 17-hydroxypregnenolone pregnenolone and testosterone. Faecal samples were freeze dried (for 48 hours) and powdered using a ball mill (Retsch MM40, Retsch, Germany). Cortisol was extracted by placing 5-10 mg of each faecal sample into a glass tube and vortexing with 2 ml methanol for 30 minutes. Following centrifugation for five minutes at 3000 rpm the supernatant was decanted into a new clean glass tube. The methanol extraction of the faecal powder was repeated and the supernatants from the two extractions pooled. A 300 µl aliquot of the methanol extract was dried down, before reconstitution in 500 µl of assay buffer. An initial ELISA confirmed specificity of the assay for use with extracted vole faecal cortisol as determined by parallelism between a serial dilution of the faecal extract and the standard curve (Rogovin & Naidenko, 2010). The dilution series was also used to ascertain the optimum volume/dilution of the extract such that the expected cortisol concentrations would fall within the range of the standard curve.

The Elisa assay was conducted as per the manufacturer's instructions. The optical density was determined with a Labtech LT-4500 plate reader at a wavelength of 405 nm and cortisol concentrations calculated using commercially available assay software (Assayzap, Biosoft Cambridge U.K.). The amount of cortisol in the faecal samples was calculated by correction for dilution and expressed in ng g^{-1} dried faeces.

Statistical analyses

All statistical analyses were conducted using R software (Version 3.5.1, The R Foundation for Statistical Computing, 2018). The effect of capture on cortisol concentration was tested using the Mann-Whitney *U* test, because the distribution of cortisol concentration did not fit a normal distribution. In the case of duration of capture, a linear mixed effect model was fitted, with faecal cortisol concentrations as the response variable and the duration of trapping as the explanatory variable. As the home range size of bank voles can range from 200 to 1600 m^2 (Koskela *et al.*, 1997), the possibility existed that voles captured within one transect at different times may be the same individual, therefore, a factor variable as a random effect was included in the model that classified observations into six groups (male and female voles captured in each of the three transects). Furthermore, analysis of the data pertaining to the time of capture and release within each transect indicated that no voles were subject to immediate recapture (and thus

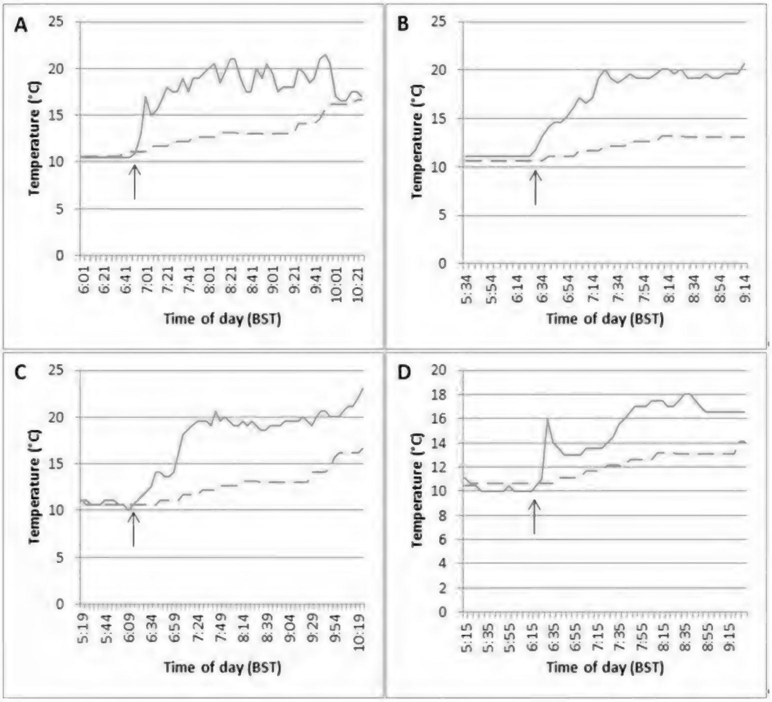

Fig. 1. Representative traces of internal trap temperature (°C) over time during the period before and after capture of bank voles (solid line) versus temperature measured in traps without capture (dashed line). All data collected 7th June 2018. The black arrows show the estimated time when the animal entered the trap.

repeated exposure to the stressor). When there was an interval between capture of a vole of the same sex within the same transect the average interval between periods of capture was 217.5 minutes (± 126.8 SD), with the shortest time difference being 102 minutes. Given the quick decrease of the glucocorticoid response after elimination of the stressor (Windle *et al.*, 1998), and the fact that gut transit time, which affects the presence of glucocorticoid metabolites in faeces (Palme *et al.*, 1996; von der Ohe & Servheen, 2002), is short in small rodents (Clemens & Stevens, 1980; Pei *et al.*, 2001), we suggest that even if repeated capture of the same individual occurred, it would not have an impact on our estimation of the effect of trap confinement.

During explanatory analyses of cortisol concentrations versus trapping duration, there was no evidence of a delay between animals entering the trap and an increase in faecal cortisol concentrations, and therefore a linear relationship was assumed thereafter. The effect of sex, body mass, and the interaction between sex and duration on faecal cortisol concentrations were also investigated. Time of day was also added as a factor variable with four levels (morning: 6:00-10:00, midday: 10:00-14:00, afternoon: 14:00-18:00, evening: 18:00-22:00), as cortisol concentrations show a circadian variation (Windle *et al.*, 1998), but it was eliminated later during model selection, together with the effect of body mass. Cortisol values were log-transformed to better fit the assumptions of the linear model that were assessed by plotting the residuals against the fitted values and by checking the normality of the residuals on a QQ-plot. The alpha level (i.e. statistical significance) was set as $P < 0.05$ and variance is represented by the standard deviation (SD), except when reporting model coefficients, where standard errors (SE) are given.

RESULTS

Trapping

The total number of captures was 39, including 37 bank voles, one wood mouse and one common shrew (*Sorex araneus*). The latter two were not included in the analysis. Double captures occurred on two occasions and in both cases one female and one male were trapped together. In two cases, the animals escaped during phenotypic assessment. In one case, only its sex was determined and in the other neither the mass nor the sex were determined. The average body mass of the trapped voles was 25.8 ± 2.22 g for males and 27.5 ± 3.07 g for females. The two sexes were equally represented and altogether we determined the cortisol values for 29 samples from trapped and 15 samples for non-trapped animals ($N_{males} = 13$; $N_{females} = 13$; $N_{undetermined} = 1$; $N_{double\ capture} = 2$). The average time that the animals spent in the traps was 128.53 ± 62.6 minutes.

Stress response to trapping

The faecal cortisol concentrations of the trapped animals did not differ significantly from those observed in the non-trapped individuals (Mann-Whitney *U* test: W = 188, $P = 0.4771$, $\text{median}_{\text{non-trapped}} = 0.23 \pm 0.21$ ng g^{-1}, $\text{median}_{\text{trapped}} = 0.25 \pm 0.24$ ng g^{-1}; Fig. 2).

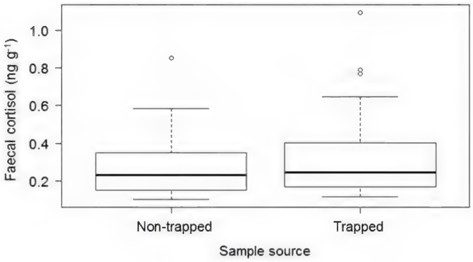

Fig. 2. Boxplot of faecal cortisol concentration (ng g^{-1}) depending on the source of the sample. The non-trapped samples were collected from non-closing traps, while trap samples were from regular captures. The boxes represent the interquartile range with medians marked with thick line, while the whiskers represent 1.5 times the interquartile range.

Stress response to the duration of being trapped

The effect of trapping duration on the faecal cortisol concentration was significant ($F_{1;12} = 5.11$, $P = 0.043$). The other variables did not have a significant effect (mass: $F_{1;12} = 0.081$, $P = 0.781$; time of day: $F_{3;12} = 0.978$, $P = 0.435$; sex: $F_{1;4} = 1.17$, $P = 0.341$; sex–duration interaction: $F_{1;12} = 2.40$, $P = 0.147$). After removing body mass and time of day as non-significant variables, the effect of trapping duration was also statistically significant, while the sex-duration interaction became marginally non-significant (duration: coef. = -0.007 ± 0.002 SE, $F_{1;17} = 7.934$, $P = 0.012$; sex: coef. = -1.004 ± 0.442 SE, $F_{1;4} = 0.929$, $P = 0.389$; sex–duration interaction: coef. = 0.006 ± 0.003 SE, $F_{1;17} = 4.329$, $P = 0.0529$). In our final model, the random effect accounted for 0.194 SD with a residual variance of 0.434. According to this model, the greater the duration of captivity the lower the faecal cortisol concentration. This effect was more pronounced in males than in females (Fig. 3). However, the interaction with sex was not significant. The data from individuals with a missing measurement for sex or mass were not included in the model.

DISCUSSION

This study investigated the effect of trapping duration on the physiological stress response of bank voles. The results obtained did not show a significant difference in the faecal cortisol concentrations in trapped voles relative to that seen in non-trapped voles but did show that cortisol concentrations decreased with the total duration of capture.

Temperature data loggers appear to be a useful tool to estimate the time when the animal entered the trap, and to calculate the exact duration of trapping. Bio-logging techniques such as this are becoming widely used

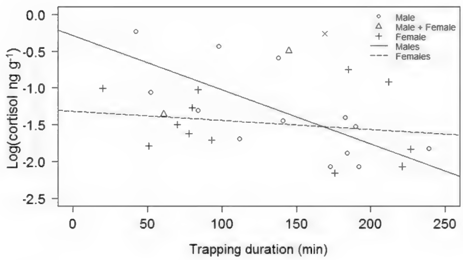

Fig. 3. Relationship between log faecal cortisol (ng g^{-1}) and trapping duration (minutes), depending on the sex of the captured animal. The continuous line shows the relationship for males and dashed line for females.

(Ropert-Coudert *et al.*, 2009; Kukalová *et al.*, 2013) and they have several advantages compared with traditional methods. In previous studies (e.g. Bosson *et al.*, 2012; Fletcher & Boonstra, 2006; Harper & Austad, 2001) the standard method of estimating trapping duration is to check the traps at given intervals to see if an animal is present or absent, which provides only a rough estimate of the actual time of capture. Time is therefore often treated as a factor variable based on the sampling interval (e.g. every four or six hours). To analyse the progression of the stress response with time, this interval should be short, which would make the work time-consuming with traditional methods, and the frequent checking of the traps could lead to an even more elevated stress responses in the animals. In contrast, ibutton™ temperature-loggers can continuously collect data for several days without any human labour. As these loggers are able to detect a 0.5 °C change in temperature they can detect the time when an animal is captured, due to the heat produced by its body compared with the background value. Moore *et al.* (2010) reported that temperature data loggers (ibutton™) were suitable to remotely monitor nest box occupancy in two possum species (western ringtail possum *Pseudocheirus occidentalis* and common brushtail possum *Trichosurus vulpecula),* and our study also demonstrates their applicability to assess trap entry with small rodent species. With this method we were able to investigate the effect of capture duration on a continuous scale, rather than comparing distinct intervals.

Cortisol was successfully detected in bank vole faecal samples using the cortisol ELISA confirming it as a non-invasive method for physiological stress assessment in this species. From a welfare aspect, this was important as it could potentially substitute the use of blood cortisol measurements and avoided use of lethal snap traps (Fletcher & Boonstra, 2006). According to our results, the faecal cortisol concentrations found in the samples collected from the trapped animals and the non-trapped animals were not significantly different, though comparison of these data is problematical: the latter, but not the former, were sampled during the night, and glucocorticoid hormone concentrations show a circadian rhythm (National Research Council, 2008). However, Windle *et al.* (1998) studied the interaction

between this rhythm and stress response, and reported that corticosteroid concentrations during the latter - in response to acute noise stress – were higher by an order of magnitude than those measured at any time before stress, which makes it very unlikely that the impact of capture-induced stress would be overwhelmed by the effect of circadian variation.

The possible explanation for the lack of difference is that trapping did not elevate cortisol concentrations. However, as the more detailed analysis showed that cortisol concentrations were negatively correlated with trap duration, this result may suggest that any physiological stress response was short-lasting and the animals habituated to the trap and therefore the effects on faecal cortisol are not apparent when mean faecal cortisol concentration was determined from multiple collected faeces. The absence of an overall trapping effect and the indication that habituation may occur in the voles in this study contrasts with previous studies of small rodents (Harper & Austad, 2001; Fletcher & Boonstra, 2006; Bosson *et al.*, 2012), where an increased stress response was seen over time. It is also possible that, after a critical duration of captivity, another peak of the stress response occurs, which may be linked to food availability or other factors. As the traps were checked at four hour intervals in this study (except in the one case of overnight trapping), the animals in our study were trapped for a much shorter time (*ca.* 128 minutes) than in previous studies and this may explain why any further cortisol response was not detected. Harper & Austad (2001) found an elevated concentration of faecal corticosteroids in red-backed voles that were trapped for four hours (*ca.* 300 ng g^{-1}) or 12 hours (*ca.* 700 ng g^{-1}), which supports our hypothesis that a more pronounced stress response can be only observed when the trapping duration is much greater than in the current study. Similar results were found by Eleftheriou *et al.* (2020) in North American deer mice: the levels of faecal corticosteroid metabolites were lower in animals confined for zero to four hours compared with a longer confinement for eight to ten hours, and were also lower than after a short restraint. It is important to note that the cortisol values obtained in this study show an overall response during the period of confinement within the trap, as opposed to the stress level of the animal by the end of the period of captivity. Therefore we cannot predict that a vole being confined for four hours should be less stressed than another one captured for half as long, but the average response (if we assume that voles defecated within the whole period) of the former should be lower. As mentioned before, this response may consist of more “peaks”: one early rise, e.g. due to the restriction of movement, which is followed by habituation, and a later one linked to the limited food availability or other factors. Habituation can also explain the pattern that we detected: the lower cortisol values associated with it can compensate the early higher response, resulting in a lower average value in animals confined for longer, while in the others we only detect the first peak, thus a higher average stress level. The best way to answer these questions and to assess how the stress response of animals changes over time would be to collect multiple droppings per animal without pooling them, making a comparison between maximum and minimum cortisol concentrations possible. For example, Rogovin *et al.* (2008) investigated faecal samples collected from trapped great gerbils (*Rhombomys opimus*) every 30 minutes during two hours of confinement, but they did not detect any corticosterone response related to time in the trap. In the same study, they also analysed seasonal and between-year variation of corticosterone levels, and reported average concentrations of 1.6 - 1.85 ng g^{-1}faeces, which is higher than the cortisol concentrations detected in our samples with the medians being 0.232 ng g^{-1} for non-trapped and 0.247 ng g^{-1} for trapped individuals. Further detailed studies like these are needed to better understand the physiological impact of short-term confinement and to design better trapping protocols.

It is also interesting that the negative effect of trapping duration was more pronounced in males than in females. In this species, both males and females maintain territories, but the territories of males are larger, and females prefer dominant males (Horne & Ylonen, 1996). Losing a territory could have a higher fitness cost for males, which could be a possible explanation why males showed an elevated stress response to capture. Or in contrast, females become less habituated to trap confinement with the time, resulting in a higher average response for the whole captive period by longer captive durations (Fig. 3). These hypotheses would need further investigation of vole behaviour.

In conclusion, we successfully used faecal cortisol to assess the stress response of bank voles to live-trapping. Similar low concentrations of faecal cortisol were found in both open and closed traps suggesting no obvious stress response to (short term) trapping but faecal cortisol was negatively correlated with trap duration, indicating that this may have been a sampling artefact due to collecting the average cortisol concentration in faeces over time. Future studies would benefit from sampling faeces from known time intervals within the trap.

ACKNOWLEDGEMENTS
We would like to send special thanks to Callum Buchanan for helping in the ELISA assay. We would also like to thank the University of Glasgow for providing funding for the project and Scottish Centre for Ecology and the Natural Environment (SCENE) for logistical support. The work was undertaken by TD in partial fulfilment for the MSc Animal Welfare Science, Ethics and Law.

REFERENCES

Abelson, K.S., Adem, B., Royo, F., Carlsson, H.E. & Hau, J. (2005). High plasma corticosterone concentrations persist during frequent automatic blood sampling in rats. *In Vivo* 19, 815-819.

Bertolino, S. & Genovesi, P. (2003). Spread and attempted eradication of the grey squirrel (*Sciurus carolinensis*) in Italy, and consequences for the red

squirrel (*Sciurus vulgaris*) in Eurasia. *Biological Conservation* 109, 351-358. https://doi.org/10.1016/S0006-3207(02)00161-1

Boonstra, R., McColl, C.J. & Karels, T. (2001). Reproduction at all costs: the adaptive stress response of male arctic ground squirrels. *Ecology* 82, 1930-1946. https://doi.org/10.1890/0012-9658(2001)082[1930:RAACTA]2.0.CO;2

Bosson, C.O., Islam, Z. & Boonstra, R. (2012). The impact of live-trapping and trap model on the stress profiles of North American red squirrel. *Journal of Zoology* 288, 159-169. https://doi.org/10.1111/j.1469-7998.2012.00941.x

Bosson, C.O., Palme, R. & Boonstra, R. (2009). Assessment of the stress response in Columbian ground squirrels: laboratory and field validation of an enzyme immunoassay for fecal cortisol metabolites. *Physiological and Biochemical Zoology* 82, 291-301. https://doi.org/10.1086/597530

Chelini, M.O.M., Otta, E., Yamakita, C. & Palme, R. (2010). Sex differences in the excretion of fecal glucocorticoid metabolites in the Syrian hamster. *Journal of Comparative Physiology B* 180, 919-925. https://doi.org/10.1007/s00360-010-0467-9

Clemens, E.T. & Stevens, C.E. (1980). A comparison of gastrointestinal transit time in ten species of mammal. *Journal of Agricultural Science* 94, 735-737. https://doi.org/10.1017/S0021859600028732

Dallman, M.F. & Bhatnagar, S. (2001). Chronic stress and energy balance: role of the hypothalamo-pituitary-adrenal axis. In: McEwen, B.S. & Goodman, H.M. (Editors.). *Handbook of Physiology. Section 7: The Endocrine System: Coping with the Environment: Neural and Endocrine Mechanisms, Vol. IV*, pp. 179–210. Oxford University Press, New York.

Dantzer, B., McAdam, A.G., Palme, R., Fletcher, Q.E., Boutin, S., Humphries, M.M. & Boonstra, R. (2010). Fecal cortisol metabolite levels in free-ranging North American red squirrels: assay validation and the effects of reproductive condition. *General and Comparative Endocrinology* 167, 279-286. https://doi.org/10.1016/j.ygcen.2010.03.024

Eleftheriou, A., Palme, R. & Boonstra, R. (2020). Assessment of the stress response in North American deermice: laboratory and field validation of two enzyme immunoassays for fecal corticosterone metabolites. *Animals* 10, 1120. https://doi.org/10.3390/ani10071120

Fletcher, Q.E. & Boonstra, R. (2006). Impact of live-trapping on the stress response of the meadow vole (*Microtus pennsylvanicus*). *Journal of Zoology* 270, 473-478. https://doi.org/10.1111/j.1469-7998.2006.00153.x

Harper, J.M. & Austad, S.N. (2000). Fecal glucocorticoids: a noninvasive method of measuring adrenal activity in wild and captive rodents. *Physiological and Biochemical Zoology* 73, 12-22. https://doi.org/10.1086/316721

Harper, J.M. & Austad, S.N. (2001). Effect of capture and season on fecal glucocorticoid concentrations in deer mice (*Peromyscus maniculatus*) and red-backed voles (*Clethrionomys gapperi*). *General and Comparative Endocrinology* 123, 337–344. https://doi.org/10.1006/gcen.2001.7682

Horne, T. & H. Ylonen. (1996). Female bank voles (*Clethrionomys glareolus*) prefer dominant males; but what if there is no choice. *Behavioral Ecology and Sociobiology* 38, 401-405. https://doi.org/10.1007/s002650050257

IUCN (2016). *The IUCN Red List of Threatened Species. Version 2016-3.* www.iucnredlist.org Accessed 7th December 2016.

Jung, T.S. (2016). Comparative efficacy of Longworth, Sherman, and Ugglan live-traps for capturing small mammals in the Nearctic boreal forest. *Mammal Research* 61, 57-64. https://doi.org/10.1007/s13364-015-0251-z

Kaufman, G.A. & Kaufman, D.W. (1994). Changes in body mass related to capture in the prairie deer mouse (*Peromyscus maniculatus*). *Journal of Mammalogy* 75, 681-691. https://doi.org/10.2307/1382516

Kenagy, G.J. & Place, N.J. (2000). Seasonal changes in plasma glucocorticosteroids of free-living female yellow-pine chipmunks: effects of reproduction and capture and handling. *General and Comparative Endocrinology* 117, 189-199. https://doi.org/10.1006/gcen.1999.7397

Korn, H. (1987). Effects of live-trapping and toe-clipping on body weight of European and African rodent species. *Oecologia* 71, 597-600. https://doi.org/10.1007/BF00379304

Koprowski, J.L. (2002). Handling tree squirrels with a safe and efficient restraint. *Wildlife Society Bulletin* 30, 101-103.

Koskela, E., Mappes, T. & Ylonen, H. (1997). Territorial behaviour and reproductive success of bank vole *Clethrionomys glareolus* females. *Journal of Animal Ecology* 66, 341-349. https://doi.org/10.2307/5980

Kukalová, M., Gazárková, A. & Adamík, P. (2013). Should I stay or should I go? The influence of handling by researchers on den use in an arboreal nocturnal rodent. *Ethology* 119, 848-859. https://doi.org/10.1111/eth.12126

Lindner, E. & Fuelling, O. (2002). Marking methods in small mammals: ear-tattoo as an alternative to toe-clipping. *Journal of Zoology* 256, 159-163. https://doi.org/10.1017/S0952836902000195

MacDonald, D. & Barrett, P. (1993). *Collins Field Guide–Mammals of Britain and Europe*. HarperCollins, London.

McEwen, B.S. & Sapolsky, R.M. (1995). Stress and cognitive function. *Current Opinion in Neurobiology* 5, 205-216. https://doi.org/10.1016/0959-4388(95)80028-X

Mellish, J.E. (2010). A preliminary assessment of the impact of disturbance and handling on Weddell seals of McMurdo Sound, Antarctica. *Antarctic Science* 22, 25-29. https://doi.org/10.1017/S0954102009990447

Mendl, M. (1999). Performing under pressure: stress and cognitive function. *Applied Animal Behaviour Science* 65, 221-244. https://doi.org/10.1016/S0168-1591(99)00088-X

Mills, J.N., Childs, J.E., Ksiazek, T.G., Peters, C.J. & Velleca, W.M. (1995). *Methods for Trapping and Sampling Small Mammals for Virologic Testing*. U.S. Department of Health and Human Services, Washington D.C, U.S.A.

Moberg, G.P. & Mench, J.A. (2000). *The Biology of Animal Stress: Basic Principles and Implications for Animal Welfare.* CABI, Wallingford. https://doi.org/10.1079/9780851993591.0000

Montiglio, P.O., Pelletier, F., Palme, R., Garant, D., Réale, D. & Boonstra, R. (2012). Noninvasive monitoring of fecal cortisol metabolites in the eastern chipmunk (*Tamias striatus*): validation and comparison of two enzyme immunoassays. *Physiological and Biochemical Zoology* 85, 183-193. https://doi.org/10.1086/664592

Moore, T., de Tores, P. & Fleming, P.A. (2010). Detecting, but not affecting, nest-box occupancy. *Wildlife Research* 37, 240-248. https://doi.org/10.1071/WR09111

Nagy, K.A., Girard, I.A. & Brown, T.K. (1999). Energetics of free-ranging mammals, reptiles, and birds. *Annual Review of Nutrition* 19, 247-277. https://doi.org/10.1146/annurev.nutr.19.1.247

National Research Council. (2008). *Recognition and Alleviation of Distress in Laboratory Animals.* The National Academies Press, Washington, DC, U.S.A.

Ortiz, R.M. & Worthy, G.A. (2000). Effects of capture on adrenal steroid and vasopressin concentrations in free-ranging bottlenose dolphins (*Tursiops truncatus*). *Comparative Biochemistry and Physiology A: Molecular and Integrative Physiology* 125, 317-324. https://doi.org/10.1016/S1095-6433(00)00158-6

Palme, R., Fischer, P., Schildorfer, H. & Ismail, M.N. (1996). Excretion of infused ^{14}C-steroid hormones via faeces and urine in domestic livestock. *Animal Reproduction Science* 43, 43-63. https://doi.org/10.1016/0378-4320(95)01458-6

Pavone, L.V. & Boonstra, R. (1985). The effects of toe clipping on the survival of the meadow vole (*Microtus pennsylvanicus*). *Journal of Zoology* 63, 499-501. https://doi.org/10.1139/z85-072

Pearson, O. (1947). The rate of metabolism of some small mammals. *Ecology* 28, 127-145. https://doi.org/10.2307/1930947

Pearson, E., Ortega, Y.K. & Ruggiero, L.F. (2003). Trap induced mass declines in small mammals: mass as a population index. *Journal of Wildlife Management* 67, 684-691. https://doi.org/10.2307/3802675

Pearson, D.E. & Ruggiero, L.F. (2003). Transect versus grid trapping arrangements for sampling small-mammal communities. *Wildlife Society Bulletin* 31, 454-459.

Pei, Y.X., Wang, D.H. & Hume, I. (2001). Selective digesta retention and coprophagy in Brandt's vole (*Microtus brandti*). *Journal of Comparative Physiology B* 171, 457-464. https://doi.org/10.1007/s003600100195

Reeder, D.M., Kosteczko, N.S., Kunz, T.H. & Widmaier, E.P. (2004). Changes in baseline and stress-induced glucocorticoid concentrations during the active period in free-ranging male and female little brown myotis, *Myotis lucifugus* (Chiroptera: Vespertilionidae). *General and Comparative Endocrinology* 135, 260-269. https://doi.org/10.1016/j.ygcen.2003.12.020

Rogovin, K.A. & Naidenko, S.V. (2010). Noninvasive assessment of stress in bank voles (*Myodes glareolus*, Cricetidae, Rodentia) by means of enzyme-linked immunosorbent assay (ELISA). *Biology Bulletin* 37, 959-964. https://doi.org/10.1134/S1062359010090098

Rogovin, K.A., Randall, J.A., Kolosova, I.E. & Moshkin, M.P. (2008). Long-term dynamics of fecal corticosterone in male great gerbils (*Rhombomys opimus* Licht.): effects of environment and social demography. *Physiological and Biochemical Zoology* 81, 612-626. https://doi.org/10.1086/588757

Romero, L.M. & Reed, J.M. (2005). Collecting baseline corticosterone samples in the field: is under 3 min good enough? *Comparative Biochemistry and Physiology A: Molecular & Integrative Physiology* 140, 73-79. https://doi.org/10.1016/j.cbpb.2004.11.004

Ropert-Coudert, Y., Beaulieu, M., Hanuise, N. & Kato, A. (2009). Diving into the world of biologging. *Endangered Species Research* 10, 21-27. https://doi.org/10.3354/esr00188

Rosatte, R.C. & MacInnes, C.D. (1989). Relocation of city raccoons. *Proceedings of the Great Plains Wildlife Damage Conference* 9, 87-92.

Stickel, L.F. (1954). A comparison of certain methods of measuring ranges of small mammals. *Journal of Mammalogy* 35, 1-15. https://doi.org/10.2307/1376067

Suazo, A.A. & Delong, A.T. (2007). Responses of old-field mice (*Peromyscus polionotus*) to consecutive days of live-trapping. *American Midland Naturalist* 158, 395-402. https://doi.org/10.1674/0003-0031(2007)158[395:ROOMPP]2.0.CO;2

Teixeira, C.P., De Azevedo, C.S., Mendl, M., Cipreste, C.F. & Young, R.J. (2007). Revisiting translocation and reintroduction programmes: the importance of considering stress. *Animal behaviour* 73, 1-13. https://doi.org/10.1016/j.anbehav.2006.06.002

Touma, C., Palme, R. & Sachser, N. (2004). Analyzing corticosterone metabolites in fecal samples of mice: a noninvasive technique to monitor stress hormones. *Hormones and Behavior* 45, 10-22. https://doi.org/10.1016/j.yhbeh.2003.07.002

von der Ohe, C.G. & Servheen, C. (2002). Measuring stress in mammals using fecal glucocorticoids: opportunities and challenges. *Wildlife Society Bulletin* 30, 1215-1225.

Weidinger, K. (2006). Validating the use of temperature data loggers to measure survival of songbird nests. *Journal of Field Ornithology* 77, 357-364. https://doi.org/10.1111/j.1557-9263.2006.00063.x

Wey, T.W., Lin, L., Patton, M.L. & Blumstein, D.T. (2015). Stress hormone metabolites predict overwinter survival in yellow-bellied marmots. *Acta Ethologica* 18, 181-185. https://doi.org/10.1007/s10211-014-0204-6

Wilson, K.R. & Anderson, D.R. (1985). Evaluation of two density estimators of small mammal population size. *Journal of Mammalogy* 66, 13-21. https://doi.org/10.2307/1380951

Windle, R.J., Wood, S.A., Shanks, N., Lightman, S.L. & Ingram, C.D. (1998). Ultradian rhythm of basal corticosterone release in the female rat: dynamic interaction with the response to acute stress. *Endocrinology* 139, 443-450. https://doi.org/10.1210/endo.139.2.5721

The Glasgow Naturalist (2021) Volume 27, Part 3, 28-41 https://doi.org/10.37208/tgn27322

Checklist of the non-lichenised fungi of Fair Isle, Scotland

R. Watling[1] & N.J. Riddiford[2]

[1]26 Blinkbonny Avenue, Edinburgh EH4 3HU
[2]Schoolton, Fair Isle, Shetland ZE2 9JU

[2]E-mail: taibnick@gmail.com

ABSTRACT
A taxonomic list of the non-lichenised fungi recorded for Fair Isle is given. The total comprises 260 taxa: 251 verified species and 9 additional intraspecific variants. Several other entities remain provisional until fresh material is available. The list is annotated with summary details of abundance, distribution, habitat, phenology and, for notable species, their wider status within Britain. Four species are new citations for the British Isles. The list demonstrates the island's regional, national, international and conservation importance, particularly for grassland taxa and montane fungi associated with dwarf willow (*Salix herbacea*).

INTRODUCTION

Fair Isle is a small, isolated island just under 8 km² in area, situated roughly half-way between Orkney and Shetland in the far north of Scotland. The earliest records of Fair Isle fungi are those of R.W.G. Dennis (RWGD). They were made between 1954 and 1986 and are mostly supported by vouchers in the fungarium at the Royal Botanic Gardens, Kew, London. In September 1985 R. Watling (RW), accompanied by Shetland naturalist Bobby Tulloch, made a two-day collecting visit as part of a wider survey of Shetland fungi. The findings were published in Watling & Riddiford (1986, 1987) and Watling (1992). The last also incorporated records of the microfungi determined by RWGD (Dennis & Gray, 1954; Dennis, 1972). As a follow-up to Watling (1992), a list of new finds for Shetland including Fair Isle was published in Watling *et al.* (2001). Subsequent records came from a six-year study, 2006-2011, by resident N.J. Riddiford (NJR) and a three-day visit in September 2011 by A. Murfitt (AM). Both focused on the "CHEGD" group of grassland taxa – *Clavariaceae*, *Hygrocybe*, *Entoloma*, *Geoglossaceae* and *Dermoloma* (Rotheroe *et al.*, 1996) – leading to publications (Riddiford *et al.*, 2019; Riddiford & Watling, 2020a,b) and an unpublished report (Murfitt, 2011). Other records, derived from *ad hoc* collections by NJR with the help from interested Fair Islanders, have remained unpublished.

Most taxa collected after 1985, and certainly the critical ones, have been scrutinised by RW from material supplied by or through NJR, along with those collected by AM. Opportunistic collecting continues to be a regular source of records with increasing input from other interested Fair Islanders. Voucher specimens and/or photographs are either held with NJR at Schoolton, Fair Isle, or in the fungarium at the Royal Botanic Garden, Edinburgh (**E**). Most records are in OS 10,000 m square HZ27. Grid references for locations mentioned in the text are given in the Appendix. Several species previously placed in *Omphalina* have been found to be lichenised but because of their agaricoid morphology we include them here. For a full list of Fair Isle lichens, see Price (2017).

With records scattered, hard to find, and some in out-of-print documents, the opportunity was taken to bring them together in this paper, both as a ready resource and as an update incorporating those not yet placed in the public domain.

LIST OF FAIR ISLE FUNGI

The list incorporates information for each species in the following order: scientific name; vernacular name(s), where known; Fair Isle status incorporating abundance, localities, substrate or habitat and fruiting body phenology – in summary form, or full dates for those rarely recorded. Additional details are given for species which achieve their northernmost known U.K. distribution and for species of particular conservation status. Nomenclature follows *Index Fungorum* (http://www.indexfungorum.org/names/names.asp) and *Mykoweb* (www.mykoweb.com). Synonyms or former names appear in parentheses after the name. Taxonomic treatment is included in square brackets where that differs from other interpretations of the taxon. Vernacular names are taken from http://www.britmycolsoc.org.uk/library/english-names/new-english-names/ and http://www.davidmoore.org.uk/Assets/fungi4schools/Reprints/ENGLISH_NAMES.pdf.
References to Schoolton with no further detail relate to sheep-grazed semi-improved grassland reverting to unimproved. References to Ward Hill with no further detail relate to the *S. herbacea* montane heath of the Ward Hill summit north flank. The expression "Hill Grazings" refers to the upland, extensively grazed, moorland in the north of the island; "in-bye" is the southern half with its richer soils, agricultural land and crofting community. All determinations are by RW except where indicated.

A. TRUE FUNGI

1. Mushrooms, brackets and relatives

AGARICOMYCETES

Agaricales

Agaricaceae

Agaricus arvensis. Horse mushroom. Common, rough grazed grassland; fruiting variable from year to year but strong productivity at end of summer drought mid-August 2018, ten days later than *Agaricus campestris* emergence. A form with great fissures in the pileus has been named *A. fissuratus* but because of merging details it has been reduced to synonymy. It has been found in north and west Scotland's maritime grasslands. Known from Ward Hill (September 1985), Kenaby, South Haven and Ditfield.

Agaricus bernardii. Salty mushroom. Common, widespread, coastal grassland, grassy banks and roadside verges adjacent to sea such as above Mavers Geo, Utra Brae and (2020) in a line of 40 on South Light Brae; Autumn, extreme dates 5th September - 27th October.

Agaricus campestris. Field mushroom. Common, very occasionally super abundant, rich soil of moderately to strongly grazed grassland, in-bye, normally late July - August; unprecedented numbers with first rains after prolonged drought from 4th August in 2018. A particularly squamulose form with slightly larger basidiospores has been separated as *A. campestris* var. *squamulosus* and is recorded from Byerwall and Barkland.

Agaricus cupreobrunneus. Copper mushroom, brown field mushroom. Frequent, widespread, in clusters, sheep-grazed grassland; fruits late August.

Agaricus macrosporus. Frequent, sometimes abundant, rough grazing; records include very large fruiting bodies near Taing, a tightly clustered row in grazed dung-rich grassland at Barkland, below The Haa, on burnside at Leogh and probably this species on a raised short-turf bank in fields east of Stonybreck; mainly mid August - late September.

Chlorophyllum rhacodes (as *Macrolepiota*). Shaggy parasol. Coastal turf and improved grassland; two records - on deep soil, enriched by sheep droppings, Pund, September 1998 and clifftop, Linni Geo, October 2014. Only Shetland record.

Coprinus comatus. Shaggy ink cap, lawyer's wig. Frequent, largely unvegetated compacted substrates such as in-bye hardcore drives and in 1989 on the Hill, a ring of 100 thrusting through hard-packed stones and soil at the Lower Station communications mast; fruits September. This is the characteristic "inky cap", but most of the other species originally placed in *Coprinus* are unrelated and therefore placed in other genera; see Psathyrellaceae.

Amanitaceae

Amanita fulva. Tawny grisette. Rare. Ward Hill, 30th August 2010. Second Shetland record.

Bolbitiaceae

Agrocybe praecox (as *A. gibberosa*). Spring fieldcap. Rare or overlooked; recorded in small numbers, grassland, at Quoy. The name *A. praecox* covers a number of forms. The present collection was identified as *A. gibberosa*, which is often considered merely a variety, although the slender build and more arachnoid veil makes it distinctive.

Bolbitius vitellinus. Yellow fieldcap. Common, widespread; rotting vegetation and weathered dung. Considered by *Index Fungorum* as junior synonym of *B. titubans* but treated separately here.

Conocybe intrusa. Accidental introduction. Single fruiting body in compost imported to island, Barkland, September 2019. Only Shetland record. *C intrusa* is a U.K. non-native recently arrived from North America, originally found in botanic gardens and greenhouses but increasingly outdoors on compost or composted soil.

Conocybe vexans. Vexing conecap. Probable accidental introduction. Around 50 fruiting bodies in several clusters, compost imported to island, Barkland, August 2019. Only Shetland record.

Conocybe watlingii. Watling's downy conecap. In discarded household material mixed with pony dung, quarry at NE corner of Boini Mire, September 1985, and on horse dung, Barkland, March 2006 and March 2008. Watling (1992) assigned the name *Conocybe neoantipus* with the comment: "This collection is very close to *Conocybe pubescens* (Gillet) Kühner". However, the differences found between the holotype of the essentially North American agaric and the Fair Isle collection are sufficient to define two species.

Clavariaceae

Clavaria fragilis (as *C. vermicularis*). White spindles. Very common, widespread, coastal grassland, roadside verges and upper slopes of Ward Hill.

Clavaria fumosa. Smoky coral, smoky spindles. Multiple clumps, roadside bank just south-east of North Grind; annual 2011-2019, 28th August - 22nd September. Two clumps on bank of ditch, Pund, 22nd October 2019.

Clavulinopsis corniculata. Meadow coral. Abundant everywhere, clifftop turf, grassland and grassy heath to Ward Hill summit, even growing through hardcore drive at the Kirk. End August - late October.

Clavulinopsis fusiformis. Golden spindles. Very common throughout, close-cropped grassland from coast to Ward Hill. September - mid October.

Clavulinopsis helvola. Yellow club. Abundant throughout, unimproved grassland and particularly heath-grassland mosaics, some apparently attached to heather (*Calluna vulgaris)* roots, September - mid October.

Clavulinopsis laeticolor. Handsome club. Occasional, unimproved grassland and heath in north, 3rd - 5th September 2011 (AM). Only Shetland records.

Clavulinopsis luteoalba. Apricot club. Possibly montane, heathy grassland, Ward Hill, 27th October 2009.

Cortinariaceae

Cortinarius albonigrellus. Moderate population, Ward Hill, 14th October 2016, amongst the moss *Mnium hornum* but will be associated with nearby *S. herbacea*, the only ectomycorrhizal host present. Apparently new

to Britain. Known from France, Norway, Finland, Russia and Turkey in montane and subalpine habitats with *Salix* spp. and other deciduous trees. Not listed by Legon & Henrici (2005) (hereafter LH) for U.K.
Cortinarius anomalus. Variable webcap. Diminutive form with *S. herbacea*, Ward Hill, 6th September 1985. A related species lacking any blue flushes, with slight viscid pileus and spores faintly ellipsoid, has been called *C. tabularis,* and possibly found on loose rocky substrate with scattered *S. herbacea* and lichens, Ward Hill, 9th September 1989.
Cortinarius possibly *caesionigrellus*. One fruiting body, Ward Hill, 30th August 2010.
Cortinarius cinnamomeobadius. An abundant, well-established colony with creeping willow (*Salix repens*) in the wet south-east corner of Chatham's Land; recorded June and September. LH treat as junior synonym of *C. croceus*.
Cortinarius cinnamomeolutescens. Heathy grassland with *S. repens* near School, September 1985.
Cortinarius fulvosquamosus. Associated with *S. repens*, School, 7th September 1985. Only Shetland record.
Cortinarius obtusus s.l. Blunt webcap. Fairly common in rough grassland, Ward Hill, September - early October. Only Shetland record. Best treated as a complex of species; see *C. scotoides* and *C. striatuloides* below.
Cortinarius phaeopygmaeus. Two fruiting bodies with *S. herbacea*, Ward Hill, 27th October 2009. Second U.K. record. The first is from Ben Macdui, Cairngorm, 2002, also montane on peaty soil with *S. herbacea*.
Cortinarius cf. *scotoides*. Two, Ward Hill, 2nd October 2011. Similar in all ways to *C. scotoides,*but possesses more rusty brown coloration. LH give one record: Cairngorm, 1984, montane, on soil. A species in the *C. obtusus* group.
Cortinarius striatuloides. With *S. repens*, September 1985. LH treat as junior synonym of *C. acutus* but is sufficiently distinct to be retained as a full species based on its lack of cheilocystidia, spores less than 10 µm long, clamp-connections, and small size of basidiomes.
Cortinarius triumphans. Birch webcap. Three fruiting bodies on *S. repens*, roadside, School, 1st September 2016. Only Shetland record.
Cortinarius trivialis. Girdled webcap. Small group with *S. repens*, wet peat and shallow pools, Chatham's Land, 4th September 1989.
Cortinarius uliginosus. Marsh webcap. Well established, *S. repens*-dominated pools, Chatham's Land; fruits early September.

Entolomataceae Pink gills. Incorporates all species previously placed in *Leptonia* and *Nolanea*, as well as *Entoloma*.
Entoloma ameides. Three fruiting bodies, flower-rich grassland, Chatham's Land, 19th August 2020.
Entoloma anatinum (as *Leptonia*). In rough grassland-heath mosaic, near School, 7th September 1985.
Entoloma atrocaeruleum. Navy pinkgill. Recorded from Schoolton, 14th September 2011 and two in short *Festuca* grassland, Vatstrass, 19th September 2020. Only Shetland records.
Entoloma atromadidum. Single fruiting body, rough grassland, near School, 28th September 2020. First Shetland record. Newly described, 2018, so wider status not yet ascertained.
Entoloma atromarginatum (as *Leptonia*). Wet heathy pasture, Ward Hill, September 1985. (See *Entoloma* nov. sp. below.)
Entoloma bloxamii. Big blue pinkgill, Bloxam's Entoloma. Near South Light HZ1982069850, 4th September 2011 (AM, as *Entoloma bloxamii* f. *bloxamii*) and rough grassland near School, 15th September 2020. First Shetland records of a nationally and internationally rare taxon. It is a U.K. BAP (Biodiversity Action Plan) species and on the provisional Red Data list. Recent studies have determined "*E. bloxamii*" as a cryptic complex of four taxa, two of which, *E. bloxami* s.st. and *E. atromadidum,* are known from Fair Isle.
Entoloma caesiocinctum (as *Leptonia*). Blue-girdled pinkgill. Roadside verge towards Bird Observatory, 6th September 1985.
Entoloma chalybaeum var. *chalybaeum* (as *Leptonia*). Indigo pinkgill. Heathy grassland near Bird Observatory HZ2193072147, September 2011 (AM).
Entoloma clandestinum (as *Nolanea*). Common throughout in sea pink (*Armeria maritima*) and sea plantain (*Plantago maritima*) dominated clifftop turf, unimproved grassland and amongst *S. herbacea* on Ward Hill; late August - mid October.
Entoloma conferendum. Star pinkgill. Commonest *Entoloma*, abundant throughout the island from *A. maritima* and *P. maritima* dominated clifftop turf and unimproved grassland to summit of Ward Hill amongst *S. herbacea*; September - October. Better known in many texts as *Nolanea staurospora*.
Entoloma corvinum (as *Leptonia*). Crow pinkgill. Schoolton, late August - September.
Entoloma elodes (often given incorrectly as *E.* "*helodes*"). Common in moorland pasture and particularly peaty marshland and mire, September. It is increasingly rare in northwest and central Europe due to habitat loss. It differs from *E. fuscomarginatum* particularly in the absence of a dark edge to the gill.
Entoloma exile (as *Leptonia pyrospila*). Roadside heading to Observatory, 6th September 1985.
Entoloma fernandae (as *Nolanea*). Grassy heath at HZ2094 73323, September 2011 (AM). Also known from coastal grassland, Sumburgh, so habitat differences (LH give unimproved grassland and coniferous woodland) possibly indicate different species within an aggregate.
Entoloma formosum (as *Leptonia*). Coastal turf, unimproved grassland and roadside verges; recorded as *Leptonia fulva* in September 1985 (RW) and as *E. formosum* s.l. with *E. formosum* s.str. at HZ22567239 in September 2011 (AM). A sienna-coloured capped form has been separated out as *Leptonia fulva* but now considered to belong to *E. formosum*. However, a diversity of field and microscopic characters suggests a complex of closely related taxa still to be resolved.
Entoloma griseocyaneum (as *Leptonia*). Felted pinkgill. Four, clifftop turf, Buness HZ2263372420, 4th September 2011 (AM).

Entoloma hebes. Pimple pinkgill. Grassy heath, south flank of Ward Hill HZ20897338, September 2011 (AM). Only Shetland record.
Entoloma infula (as *Nolanea*). Schoolton, 29th September 2006.
Entoloma juncinum (as *Nolanea*). Schoolton, 25th September 2008.
Entoloma lividocyanulum (as *Leptonia*). Frequent, Schoolton, and two, clifftop, Field HZ2111771524, 5th September 2011 (AM). Only Shetland records.
Entoloma ?ochromicaceum. Schoolton, 14th September 2011. Two other U.K. records, Beinn Eighe, Wester Ross and Schiehallion, Perthshire, both in 2000.
Entoloma ortonii. Two fruiting bodies, 14th September 2011, Schoolton. Described from Shetland under the name *Nolanea farinolens*.
Entoloma papillatum (as *Nolanea*). Papillate pinkgill. Frequent, damp unimproved grassland, Hill Grazings, 4th September 2011 (AM). Recognised by the papillate, brown pileus and white immature gills.
Entoloma porphyrophaeum. Lilac pinkgill. Common, widespread, coastal grassland, heathy pastures and cliff top, 5th September 2011 (AM).
Entoloma prunuloides. Mealy pinkgill. Common, widespread, roadside verges and sheep pasture, September. *E. prunuloides* var. *obscurum* was recorded in clifftop heathy grassland, Furse, 5th September 2011 (AM). Only Shetland record.
Entoloma pseudoturci. Schoolton, 23rd September 2006. Only Shetland record. This species would be placed in *Leptonia* if the segregate genera were accepted.
Entoloma sericellum (as *Leptonia* and *Alboleptonia*). Cream pinkgill. Common, coastal heath, well-drained acid grassland, sheep pasture and moorland to Ward Hill summit. Early September.
Entoloma sericeum (as *Nolanea*). Silky pinkgill. Widespread throughout, often in large numbers, grazed grassland from clifftops to Ward Hill summit, mid July - early September. Three forms have been recognised: *E. sericeum* var. *sericeum* at HZ2089573376 and HZ2256572397, September 2011 (AM); *E. sericeum* var. *cinereo-opacum*, three at HZ2063070658, 3rd September 2011 (AM); only Shetland record; described for collections with an overall greyish coloration, even when drying; and *E. sericeum* var. *nolaniforme*, Schoolton, 26th August 2009 and Rippack HZ20647064, 3rd September 2011 (AM); only Shetland records; restricted to *E. sericeum* with the outward form of a *Nolanea*.
Entoloma serrulatum (as *Leptonia*). Blue edge pinkgill. Common, heathy pastures, as at Lower Station HZ21097321 and coastal grassland, as at Springfield. September.
Entoloma solstitiale (as *Nolanea*). Heathy grassland near Kirk, 3rd September 2011 (AM). Very close to *E. conferendum* but differs in the 4-sided, not distinctly stellate basidiospores and lack of mealy taste.
Entoloma undatum (as *Eccilia*). Schoolton, 26th September 2011. Only Shetland record.
Entoloma vernum (as *Nolanea*). Early spring pinkgill. Abundant but localised, late August - early September. Includes exceptional swarms of hundreds in *A. maritima* and *P. maritime* dominated coastal turf and coastal grassland at North Light, 8th September 1989.
Entoloma sp. Coastal grassland, Buness, 4th September 2011. Like *E. papillatum* but with distinctive dark edge to gills; likely to be a new species, not currently described according to AM/RW.

Hydnangiaceae
Laccaria laccata. Deceiver. Frequent, wet acid to base-rich soils including Quoy and Springfield flush, June 2019. It differs from *L. proxima* in the globose spores. There is much variation within this taxon and some forms have been given specific identity, including a montane form. This variation is now considered insufficient.
Laccaria proxima (as *Laccaria proximella*, Mountain deceiver). Scurfy deceiver. Abundant as well as frequent at its one known site, north flank of Ward Hill. Mid-September to mid October.

Hygrophoraceae Waxcaps
Arrhenia cf. *parvivelutina*. Ward Hill, on base-poor peaty soil, 6th September 1985. This differs from original description in lack of clamp-connections. Not in LH.
Cuphophyllus flavipes (as *Hygrocybe*). Yellow foot waxcap. One record, unimproved acidic grassland, September 2011 (AM). Recorded undoubtedly as *H. lacma* for Mainland Shetland.
Cuphophyllus pratensis (as *Hygrocybe*). Meadow waxcap. The island's commonest waxcap, very abundant throughout, unimproved, generally dry grassland from littoral to Ward Hill summit, end August - September and residually to early December. An overall ivory-coloured pale form – which has been called *Hygrocybe pratensis* var. *pallida* (synonym: *Hygrocybe berkeleyi),* pale waxcap or white meadow waxcap – is infrequent in sheep walk and unimproved grassland, as at Schoolton. September - early October.
Cuphophyllus russocoriacea (as *Hygrocybe*). Cedarwood waxcap. Schoolton, 6th October 2011.
Cuphophyllus virgineus (as *Hygrocybe*). Snowy waxcap. Common, unimproved and coastal grassland, including clifftops, September. The form with smaller stature, which is common on Fair Isle, has been traditionally separated as *Hygrocybe nivea*. Pinkish mottled fruiting bodies are frequently seen and have been called var. *roseipes* but it has been shown that the coloration is due to colonization by the fungus *Fusarium sporotrichioides*.
C. virginea var. *fuscescens*. Schoolton, 30th August 2011. Only Shetland record. Formerly considered a separate species.
Gloioxanthomyces vitellinus (as *Hygrocybe*). Possibly montane on acidic soils, Lower Station to Ward Hill, 5th September 2011 (AM).
Gliophorus irrigatus (as *Hygrocybe*). Slimy waxcap. Common, widespread in unimproved grassland, sheep walk and rough grassland-heath mosaic, first half of September.
Gliophorus laetus (as *Hygrocybe*). Heath waxcap. Abundant, often in large, dense groups on rather acidic,

dry free-draining close-cropped grassland from low altitude to summit of Ward Hill, September-October.
Gliophorus psittacinus (as *Hygrocybe*). Parrot waxcap. Abundant throughout, unimproved grassland from littoral sites to Ward Hill summit, September - mid October. The concept adopted here is that of LH. Subsequent molecular studies have demonstrated the existence in British material of several cryptic species within a complex.
Hygrocybe aurantiosplendens. Orange waxcap. Two fruiting bodies, Schoolton, 19th September 2010. Close to *H. quieta,* which has similar spores but possesses an oily smell when rubbed and a more viscid pileus at first with less pronounced red.
Hygrocybe acutoconica var. *acutoconica* (as *Hygrocybe persistens*). Persistent waxcap. Relatively common, widespread, unimproved and maritime grassland, September.
Hygrocybe cantharellus. Goblet waxcap. Common, widespread, unimproved grassland, second half of September. Only Shetland records.
Hygrocybe ceracea. Butter waxcap. Very common, widespread, in-bye to Ward Hill summit, unimproved and maritime grassland, late August - mid October. Characterised by a viscid to greasy pileus but dry stipe.
Hygrocybe chlorophana s.str. Golden waxcap. Highly abundant, unimproved and maritime grassland, late August - early October.
H. chlorophana var. *flavescens* (= *H. euroflavescens*). Often intermixed with *H. chlorophana* s.str., is also very common in roadside verges and grassland, noted at Buness, Chatham's Land, School and Schoolton, mid July - early October. These orange-yellow coloured forms have received full status as *H. flavescens* but are now considered no more than a variety.
Hygrocybe coccinea. Scarlet waxcap. Highly abundant, widespread, semi-improved and unimproved grassland, coastal turf and heath, early September - mid October. *H. coccinea* typically possesses a convex pileus but a distinctly umbonate variety has been bestowed the name *H. coccinea* var. *umbonata* – recorded at Schoolton, 11th October 2010.
Hygrocybe conica. Blackening waxcap. Abundant, widespread. Semi-improved and unimproved grassland, early September. This has been demonstrated recently to comprise a mixture of cryptic species.
Hygrocybe conica var. *pseudoconica* (= *H. nigrescens*). *S. repens* rich grassy heath near School, September 1985. This differs in its more robust stature and distinctly white base to the stipe. It is considered by some authorities to be a form of *H. conica* associated with *S. repens* beds.
Hygrocybe glutinipes. Glutinous waxcap. Frequent, unimproved bryophyte-rich grassland, end August - October; records include a substantial colony in maritime grassland with scattered prostrate heather, lower slopes of Hoini, 16th October 2014. Its occurrence is known to be associated with the presence of pleurocarpous mosses.
Hygrocybe helobia. Garlic waxcap. Very common, widespread, in-bye to Ward Hill summit, unimproved grassland, particularly amongst moss on wet soils, sometimes in crowded patches, mid July - mid September.
Hygrocybe insipida. Spangle waxcap. Frequent, widespread, in-bye to Ward Hill north flank, acidic soil in unimproved grassland as well as neutral or relatively base-rich grassland and grassy areas, end August - late October. European Red List species.
Hygrocybe miniata. Vermilion waxcap. Very common, widespread, unimproved grassland and grassy heath, mid July to early October; records from roadside between Observatory to School, the Rippack, Schoolton and Chatham's Land. A form described from Britain (*Hygrophorus strangulatus:* orange-red waxcap) by Orton (1960) has strongly constricted basidiospores; this is not considered sufficiently distinct and Arnolds (1986) considers this to be the same as Fries' concept of *Agaricus* (= *Hygrophorus*) *miniatus.*
Hygrocybe mucronella. Bitter waxcap. Known from Schoolton, late August - mid September. Well characterised by the bitter taste and better known as *H. reai.*
Hygrocybe punicea. Crimson waxcap. Common, particularly along roadside verges, September - October.
Hygrocybe quieta. Oily waxcap. Relatively common, widespread, neutral unimproved and coastal grassland; records include Buness, Schoolton and roadside between School and Bird Observatory, end August - early October. European Red List species. An odourless form found at Schoolton, 30th August 2008 and 26th September 2016, has been equated with the concept of *H. obrussea* adopted by Orton (1960).
Hygrocybe reidii. Honey waxcap. Infrequent, scattered, unimproved grassland and sheep walk, September to mid October. Has been confused with *H marchii* in Britain.
Hygrocybe, probably *saliceti-herbaceae*. With *S. herbacea*, montane heathy grassland and loose soil, Ward Hill, 11th October 2009.
Hygrocybe turunda. Schoolton, 18th September 2006. The concept adopted is that of Orton (1960) and Moeller (1945); see Watling (1992).
Lichenomphalia flava (as *L. luteovitellina*). Sunburst lichen. Unimproved montane grassland, *S. herbacea* zone, Ward Hill, predominantly May - August. Also recorded from clifftop grassland, north coast, 2nd June 2015 in Price (2017) as *L. alpina*, an alternative name reflecting its habitat preferences. It is not uncommon elsewhere in Shetland.
Lichenomphalia umbellifera (as *L. ericetorum*). Heath navel. Abundant all year, damp peat substrates, particularly wet eroded overhangs, sea level to Ward Hill summit; recorded as frequent and widespread in Price (2017). *Omphalina fulvopallens,* described from Scotland and applied to over-all pale coloured specimens with two-spored basidia from boggy areas, is now considered a synonym; it has been found on Ward Hill.
Lichenomphalia hudsoniana. Arctic mushroom scales. Montane, Ward Hill, anamorphic (asexual) *Coriscium* state, 6th September 1985; also recorded in Price (2017), 2nd June 2015. This taxon was described from North America; in Britain it is probably better known as

Omphalina luteolilacina, under which name it is recorded from many sites elsewhere in Shetland.

Lichenomphalia velutina (as *Omphalina grisella*). On base-poor soil by trackside in short moss cover between Bird Observatory and School, September 1985. Only Shetland record.

Porpolomopsis calyptriformis (as *Hygrocybe calyptriformis*). Pink ballerina, pink meadow-cap, ballerina waxcap. Rare or overlooked, one record; fruiting body, low rough acid grassland, edge of airstrip, 22nd September 2019.

Hymenogastraceae

Galerina cerina (as *G. cerina* var. *longicystis*). Peaty soil, Ward Hill, September 1985. First U.K. record.

Galerina clavata. Ribbed bell. Two, on soil amongst mosses in grassy area, north flank of Ward Hill, 27th October 2009.

Galerina hypnorum. Moss bell. Dry heath, Rippack close to Kirk, 7th September 1985. Best treated as one of a complex of species.

Galerina paludosa. Bog bell. One record (but probably more widespread), small group, saturated *Sphagnum*-rushy grassland, Lower Station, 12th August 2018.

Galerina pseudomniophila. Five basidiomes, all within 100 cm, loose rocky substrate covered in *S. herbacea* and lichens but few flowering plants, Ward Hill, 9th September 1989.

Galerina pseudomycenopsis. Widespread known from coastal grassland, unimproved grassland (Schoolton) and Ward Hill, second half of August. First evidence was small clump, Meoness, 22nd August 2001. Recorded for Mainland Shetland as *G. pseudopumila*.

Galerina pumila. Dwarf bell. Widespread, frequent, mid September to early November; can be plentiful e.g. numerous, Ward Hill, October 2009 and 2011, and *ca.* 15 in line amongst hypnum moss (*Hypnum cupressiforme*), Tarryfield, 5th November 2019. Commonly appears as the synonym *Galerina mycenopsis.*

Galerina subcerina. Peat soil, Barkland, September 1985.

Galerina terrestris (*sensu* Watling). Schoolton, 11th October 2010. This agrees in all ways with material from south Norway; it differs from *G. vittiformis* in the four-spored basidia and presence of ring-zone.

Galerina vittiformis. Hairy-leg bell. Common, Schoolton, late August - mid September. Easily recognised by the distinctly roughened basidiospores, prominent caul-, cheilo- and pleurocystidia but lack of similar cells on pileus. Commonly recorded in literature as *G. rubiginosa*.

Hebeloma mesophaeum. Veiled poison-pie. Plentiful amongst bryophytes, Ward Hill, 14th October 2016.

Psilocybe semilanceata. Liberty cap. Abundant throughout, semi-improved and dung-rich grassland, late August - September.

Psilocybe subcoprophila. Rare or overlooked; one record on dung, September 1985. Previously not always separated from *P. coprophila*, which differs in the much larger basidiospores.

Psilocybe subviscida (as *P. bullacea*). Occasional, Schoolton; also known (as a cluster of four) from Chatham's Land; mid August - September. Recent research has shown that *P. subviscida* is rather variable and "*P. bullacea*", previously treated as independent, now has varietal status as *P. subviscida* var. *velata*. The species is easily confused with *P. montana*.

Inocybaceae

Inocybe fulvella. One record, with *S. herbacea*, Ward Hill, September 1985. Only Shetland record.

Lycoperdaceae

Bovista nigrescens. Brown puffball. Common, widespread, horse and sheep grazed coastal and acid grassland, clifftops to Ward Hill, late August - mid October.

Bovista plumbea. Grey puffball. Frequent, semi- and unimproved grassland, also, growing through compressed unmetalled track, Rippack, August - early September.

Lycoperdon excipuliforme. Pestle puffball. Four, roadside grass verge, Schoolton, 11th September 2014. Only Shetland record.

Lycoperdon nigrescens. Dusky puffball. *Empetrum*/*Calluna* heath, edge of airstrip and Ward Hill summit, September - early October.

Lycoperdon molle. Soft puffball. *S. repens* turf on peaty stony ground, near Schoolhouse, September 1985. Second Shetland record.

Vascellum pratense. Meadow puffball. Common, in-bye and north, coastal turf, unimproved acid grassland and roadside verges, late July - early September.

Lyophyllaceae

Calocybe gambosa. St. George's mushroom. Common at four known sites: grass verges at Quoy and at Wirvie, close-cropped maritime grassland above Hesti Geo and clifftop grassland at Kirki Geo, mid May - early June.

Rugosomyces carneus (as *Calocybe*). Pink domecap. Frequent, roadside verges, e.g. roadside heading to Observatory, near Taing, September.

Tephrocybe palustris. Sphagnum greyling. Clump of four, edge of very wet *Sphagnum* bog, Swey, 9th September 1989.

Marasmiaceae

Marasmius oreades. Fairy ring mushroom, fairy ring champignon. Two small clusters on clifftop, Linni Geo, 28th June 2015, one at roadside, Quoy, 16th June 2017 and two clumps at side of track, Midway, 25th May 2020.

Mycenaceae

Mycena aetites. Drab bonnet. Widespread including close-cropped grassland at Schoolton, montane heath grass mosaic on north flank of Ward Hill summit and prostrate *Calluna* heath at Malcolm's Head, end August - end October.

Mycena epipterygia. Yellowleg bonnet. Widespread, acidic grassland and heath, September. Noted for the glutinous, yellow stem.

Mycena filopes. Iodine bonnet. Frequent on and under prostrate juniper (*Juniperus communis* ssp. *nana*),

Swey, Breed Piece and Byerwall, October - mid November.
Mycena flavoalba. Ivory bonnet. Known from Schoolton, end September - early October.
Mycena leptocephala. Nitrous bonnet. Schoolton, 11th September 2006. LH report this species as "on soil or decayed leaf and woody litter (twigs, etc.) in deciduous and coniferous woodland….". Its appearance in grassland relates to *S. repens* – a widespread component of grassland in Fair Isle.

Omphalotaceae
Gymnopus dryophilus. Russet toughshank. Frequent from Setter north to Ward Hill summit, *Empetrum*/*Calluna* moorland and montane heath, September - mid October. Better known as *Collybia dryophila*. Fruiting body on Ward Hill parasitised by the fungus *Syzygospora* (*Christiansenia*) *mycetophila* q.v.
Gymnopus alpinus. Alpine toughshank. One record: two fairy rings in close proximity, dry prostrate *Calluna* heath, south-facing aspect, Rippack, 20th May 2011. A recently described Arctic-alpine species now known to be widespread in montane areas of Scotland including Shetland. U.K. conservation status: notable.

Pluteaceae
Pluteus cervinus. Deer shield. One record: on buried wood, overgrown garden, Schoolton, 27th January 2009.

Psathyrellaceae
Coprinopsis cordispora (as *Coprinus*). On fresh dung, Ward Hill, 2nd October 2011.
Coprinopsis laanii (as *Coprinus*). Loosely tufted group, oil-soaked wood chippings and old sawdust, car pit, Shirva, 24th January 2000. Only Shetland record.
Coprinopsis lagopides (as *Coprinus* and *Coprinopsis jonesii*). Post-fire inkcap. Sparsely vegetated ground at two localities: School grounds and Lower Stonybreck, March 2019; a second "crop" at Lower Stonybreck a month later. Only Shetland records.
Coprinopsis tuberosa (as *Coprinus*). Tuberous inkcap. One record, plentiful on rotted manure in garden, Barkland, 10th August 2020. Only Shetland record.
Psathyrella panaeoloides. Schoolton, 23rd September 2006.

Schizophyllaceae
Schizophyllum commune. Splitgill. A recent colonist first recorded, group of 12, facing east on sea-borne soft wood trunk lifted from sea a few months earlier, Quoy, 10th October 2015, followed by three autumn records in 2020: *ca.* six on exposed weathered silage, Midway, 17th September 2020; two clusters, growing from slits in silage bags, Quoy, 4th October 2020; one on year-old silage, Setter *ca.* 12th October. Northernmost U.K. records. *S. commune* has come a long way from being rare in mid-20th century to expanding its range throughout the U.K. with a special liking for exposed silage.

Strophariaceae
Deconica Horizontalis. Wood oysterling. Rare, one record: four fruiting bodies on underside of wooden ladder, Finniquoy gully, 18th July 2015. Only Shetland record. Better known as *Melanotus*, a genus based on the pleurotoid aspect of the fruiting bodies.
Deconica inquilina. Flecked brownie. Common at Schoolton; first evidence, 14th September 2008, end August - end September. Only Shetland records.
Deconica montana. Mountain brownie. Common, known from Lower Stonybreck (roadside) and Schoolton, mainly September but outlier 20th February 2018. The Schoolton samples include material with slightly larger basidiospores, a form sometimes separated as "*Psilocybe physaloides*" but not now considered worthy of separation.
Hypholoma elongatum. Sphagnum brownie. Known from acidic bog, Sukka Mire, 6th September 1989.
Hypholoma ericaeoides. Common, wettest parts of *Sphagnum* bog across Hill, e.g. *ca.* 20, scattered in the wettest part of a very wet *Sphagnum* bog, Swey, 9th September 1989.
Hypholoma ericaeum. Frequent in moss on wet peaty soil, e.g. Byerwall, September.
Hypholoma fasciculare. Sulphur tuft. Rare, one record: two clusters, base of fence post, 6th April 2019.
Hypholoma subericaeum. Occasional, widespread, on disturbed soil; classically in swarms of 100 or more amongst rotting vegetation thrown up during ditch excavations, September - October.
Protostropharia semiglobata (as *Stropharia*). Dung roundhead. Abundant across the island on weathered dung, grassland, heath and clifftops, June - early November. A collection on pony dung, NE Boini Mire quarry, 7th September 1985, was identified as var. *stercoraria* because of its flattened pileus and large size but it does not warrant separation.

Agaricales: Family uncertain. The listing of the genera of Agaricales below is not intended to mean that they possess a close relationship to each other, but only that they cannot, as yet, be placed in the main classification of agarics.
Gamundia striatula. Lined meadowcap. Grazed maritime grassland, Buness, September 1985.
Lepista multiformis (as *L. multiforme*). Fruiting bodies frequent and abundant at four known sites: amongst hypnum moss, crowded, *ca.* 100 within 30 m radius, on mossy part of airstrip in 1989; neutral grassland at Eas Brecks in 2013; maritime grassland at Hjukni Geo in 2013 and 2019; and base of Hoini in 2020. Arctic-alpine species, rare in U.K. This taxon differs from *L. ovisporum*, of which there is a possible collection from Fair Isle, in its more robust habit and larger basidiospore size.
Lepista nuda. Wood blewit. Common, strictly coastal, rocky south-facing slope, Utra Brae, under cliff edge above Hesti Geo, Swarts Geo, above North Haven beach, Bullock Holes, above North Naaversgill, edge of Grand Canyon (Breed Piece); rarely from early October but normally end October - early December.

Lepista panaeola. Rare, single record: acid grassland/heather mosaic, above Wester Lother, 9th November 2019.
Melanoleuca schumacheri. Clouded cavalier. Close cropped acidic grassland, Airstrip roadside verge, 14th October 1989.
Tricholomopsis rutilans. Plums and custard. Occasional, rotting fence post, disturbed soil and well-drained grassland, Vaadal Plantation, Bullock Holes, Wirvie, Barkland, mid August - late September.
Panaeolina foenisecii. Brown mottlegill, brown haycap. Abundant throughout island, dung-rich grazed grassland, mainly mid July into October.
Panaeolus acuminatus. Dewdrop mottlegill. Schoolton, 9th October 2011. Determination as outlined by Hora (1957); it is difficult to separate from *P. rickenii* q.v., except the basidiome is generally not as slender and the pileus broader and often with a constriction toward the apex.
Panaeolus fimicola. Turf mottlegill. Common, Schoolton, late August - early October. A very dark form that has been separated as *P. ater* found at Schoolton, two basidiomes on 23rd September 2006 and at Valsbrough, two on 26th April 2019.
Panaeolus rickenii. Very common, dung-enriched grassland, Observatory to School and Schoolton, mid September - early October. Although LH treat this as a junior synonym of *P. acuminatus*, in our view it is sufficiently distinct to remain as a separate species.
*Panaeolus semiovatus***.** Dung mottlegill. Very common, grassland on dung, including pony dung middens at Boini Mire and Barkland; also recorded Kenaby, Quoy and near School; all months, particularly in spring.
Panaeolus papilionaceus. Petticoat mottlegill. Dung-rich semi-improved grassland at Schoolton, September. This species is perhaps better known as *P. sphinctrinus*.

Auriculariales
Auriculariaceae
Auricularia auricula-judae. Jelly ear, Jew's ear fungus. Short-lived introduction. Colony on slab of heart-wood or teak set in a concrete base, new slipway, North Haven, 4th June 2001. Only Shetland record.

Boletales
Hygrophoropsidaceae
Hygrophoropsis aurantiaca. False chanterelle. Known from a solitary example in damp, poor grazing pasture mainly of moss and *S. repens,* Rippack, 4th September 1989.

Cantharellales
Hydnaceae
Clavulina cinerea. Grey coral. Localised, montane, several small "swarms" in grassland with *S. herbacea*, Ward Hill, 6th September 1985.

Hymenochaetales
Rickenellaceae
Rickenella fibula. Orange mosscap. Common at Schoolton, also known from Ward Hill, end August - mid September. Better known and cited in many texts as *Mycena* or *Omphalina fibula*.
Rickenella swartzii. Collared mosscap. Common, Schoolton, mid - end September.

Polyporales
Fomes fomentarius. Hoof fungus, tinder bracket. Short-lived adventive. On driftwood, probably birch (*Betula* sp.), undated but late 20th century. Specimen destroyed when wood burned on croft house fire. Only Shetland record.
Gloeophyllum sepiarium. Conifer mazegill, rusty-gilled polypore. Infrequent; an efficient "rotter", destroying pine framework to windows and walls, older buildings, in-bye; dated records from Lower Stonybreck, 6th March 1998 and colony on window frame of old hut, Quoy, 13th August 2014. Only Shetland records.

Russulales
Bondarzewiaceae
Heterobasidion annosum. Root rot, root fomes. Base of *ca.* 50 year old fence post, probably of larch (*Larix* sp.), Quoy, 18th June 1996. Only Shetland record.

Russulaceae
Lactarius lacunarum. Very common with *S. herbacea*, Ward Hill and *S. repens* at Chatham's Land and roadside near Kirk, first half of September.
Lactarius lanceolatus. Abundant. Montane grassland and stony *S. herbacea*-lichen heath, Ward Hill, August - November, peaking October. Annual, first recorded 19th August 1998. Second U.K. and Shetland record (Arctic-alpine).
Russula densifolia. Crowded brittlegill. Several on stony *S. herbacea* heath, Ward Hill, 11th and 14th October 2016. Only Shetland records.
Russula felleaecolor. Plentiful, Ward Hill, 2nd October 2011. First confirmed British record. Described originally from the Italian Alps.
Russula fragilis. Fragile brittlegill. With *S. repens*, Rippack and Rippack clifftop, 7th September 1985.
Russula medullata. Occasional amongst *S. herbacea*, Ward Hill; first evidence September 1985; small numbers at same site, 17th October 2008, 11th and 12th October 2009. Only British records (Arctic-alpine). Agrees in all ways with collections of this agaric, recently described from arctic alpine communities (Kühner, 1975).
Russula nana. Alpine brittlegill. Common, stony *S. herbacea*-lichen heath, Ward Hill and alongside semi-permanent rain pools, moss, lichen and *S. repens* rich wet grassland on the Rippack; probably associated with roots of *Salix*; October. Formerly treated, including in Watling (1992), incorrectly as *R alpina*.
Russula norvegica. Occasional, Ward Hill, September - October; first evidence September 1985. U.K. Red Data List. One other Shetland record. LH treat this as junior synonym of *R. laccata,* but some authorities considered *R. norvegica* distinct – an opinion followed here.
Russula pallescens. Three, one fresh, Ward Hill, 13th September 2017. Second U.K. record.
Russula pascua. Pasture brittlegill. With *S. repens*, Rippack and *S. herbacea*, Ward Hill, September - mid October. Full distribution unclear but recorded from

many montane areas of Scotland and common in Shetland.
Russula persicina. Weathered basidiomes recorded, Ward Hill, September 1985.

Thelephorales
Thelephoraceae
Thelephora terrestris. Earth fan. Short-term introduction, probably with compost or trees; colony on soil and base of trunk, imported oak (*Quercus* sp.) sapling, in pot outside house, Lower Stonybreck, 9th July 2001. Did not persist.

2. Jelly fungi
DACRYMYCETES
Dacrymycetales
Dacrymycetaceae
Calocera viscosa. Yellow stagshorn. On timber from derelict war-time building, Ward Hill, September 1985. Very unusual on worked wood. Second Shetland record.
Dacrymyces stillatus. Common jellyspot. Relatively frequent on decaying worked wood, planks and old untreated fence posts. All year.

EXOBASIDIOMYCETES
Tilletiales
Tilletiaceae
Tilletia sphaerococca. On common bent (*Agrostis capillaris*), Ward Hill, 30th July 2004. Second Shetland record.

TREMELLOMYCETES
Tremellales
Carcinomycetaceae
Syzygospora mycetophila. Collybia jelly. Parasitic on *Gymnopus dryophilus* (=*Collybia dryophila*), Ward Hill, 14th October 2016. Only Shetland record.

3. Rust fungi and smuts
PUCCINIOMYCETES
Pucciniales
Coleosporiaceae
Coleosporium tussilaginis. Frequent. On various eyebrights including *Euphrasia arctica* and *E. foulaensis*, August. Sometimes treated as separate entity, *C. rhinanthacearum*.

Gymnosporangiaceae
Gymnosporangium clavariiforme. Tongues of fire, juniper rust. Substantial colony on single prostrate juniper, Breed Piece, 9th April 2010. Only Shetland record.

Melampsoraceae
Melampsora epitea. Willow leaf rust. Common, particularly around the School, on *S. repens* leaves, often in heavy clusters of orange spots, July-August.
Melampsora caprearum. Goat willow leaf rust. Rare, on leaves of introduced *Salix* cf. *cinerea*, Vaila's Trees, 11th September 2019. Only Shetland record.

Pucciniaceae
Puccinia arenariae. On leaves of red campion (*Silene dioica*), garden, Schoolton, 25th June 2009. Probably under-recorded.
Puccinia obscura. Occasional. On field wood-rush (*Luzula campestris*), summer. Alternate host is common daisy (*Bellis perennis*), which is common on island.
Puccinia punctiformis. Thistle rust. Very common, on creeping thistle (*Cirsium arvense*), mid June - August, peaking July.
Puccinia urticata. Nettle clustercup rust. Common, occasionally as heavy gall infestations, on nettles (*Urtica dioica*) (aecidial stage) at Pund and Bullock Holes, mid - late June. This is a member of the *P. caricina* complex with alternate hosts sedges (*Carex* spp.).

Pucciniastraceae
Melampsorella caryophyllacearum. Reported by RWGD with no further detail.

USTILAGINOMYCETES
Ustilaginales
Microbotryaceae
Microbotryum violaceum (as *Ustilago violacea*). Reported by RWGD, undated, on anthers of sea campion (*Silene maritima*).

Ustilaginaceae
Ustilago striiformis. Stripe smut of grasses. On Yorkshire fog (*Holcus lanatus*), roadside, in-bye, 19th September 2016. Probably common but overlooked.

4. Cup fungi and relatives
PEZIZOMYCETES
Geoglossales
Geoglossaceae
Geoglossum barlae. Rare, lower slopes of Ward Hill, September 2011 (AM). Only Shetland record. Vulnerable, according to the Fungi Red Data list for Britain and Ireland.
Geoglossum cookeianum. Earthtongue. Frequent in acidic grassland, slopes of Ward Hill, 5th September 2011 (AM).
Geoglossum fallax. Deceptive earthtongue. Occasional, sometimes abundant as at Kenaby where hundreds scattered through dry well-drained close-cropped grassland in late October 1989; also known from Ward Hill summit north flank; October.
Geoglossum nigritum. Scarce. Mossy heath, September 1985. Probably one of Britain's commonest earthtongues.
Geoglossum starbaeckii. Star earthtongue. Rare, single spike on saturated soil, mat-grass (*Nardus stricta*) dominated acid grassland, clifftop, Rippack, 19th September 1998. Only Shetland record.
Geoglossum umbratile. Plain earthtongue. Scattered, mossy grassland in north, 3rd and 5th September 2011 (AM). Only Shetland records.
Microglossum olivaceum. Olive earthtongue. Several groups of two to three spikes per group, buck's-horn plantain (*Plantago coronopus*)-red fescue (*Festuca rubra*) coastal turf, free draining clifftop slope, Utra

Brae overlooking Shalstane, 18th September 1998; fruiting bodies appeared to be attached to the plantain. First for Shetland, fifth Scottish record. On the Red Data list and a U.K. BAP species.

Helotiales

Drepanopezizaceae

Leptotrochila cerastiorum. Reported by RWGD, undated, on fading leaves of common mouse-ear chickweed (*Cerastium fontanum*). Only Shetland record.

Erysiphaceae

Erysiphe knautiae. Scabious mildew. Probably common, widespread, on devil's-bit scabious (*Succisa pratensis*) leaves, rough grassland, late summer - autumn.

Gelatinodiscaceae

Phaengellina empetri. On dead attached leaves of crowberry (*Empetrum* sp.), September 1985. Probably common but overlooked.

Helotiaceae

Hymenoscyphus calyculus. Rare or overlooked, several on stick in garden, Barkland, 10th July 2020. Only Shetland record.

Sclerotiniaceae

Myriosclerotina curreyana. Probably widespread but overlooked, known on jointed rush (*Juncus articulatus)*, waterlogged mires and flushes, Sukka Mire and Springfield, June.

Pezizales

Ascobolaceae

Ascobolus denudatus. Three on soil among potato shards, garden, Lower Stonybreck, 24th September 2001. Only Shetland record.

Ascobolus furfuraceus. Reported by RWGD, undated, with no further detail.

Saccobolus obscurus. Reported by RWGD, undated, on sheep droppings.

Saccobolus versicolor. Reported by RWGD, undated, on rabbit pellets.

Pezizaceae

Iodophanus carneus. Widespread, on dung.

Peziza cerea. Cellar cup. Infrequent, wet plasterboard in out-buildings and damp housing; Nissen hut, 1981, North Haven; inside lounge wall, Schoolton, 7th June 1995 and other side of same wall, Schoolton kitchen, 12th July 1995.

Peziza domiciliana. Carpet cup, domicile cup fungus. Several fruiting bodies clustered on soil, grassland half-buried with cast-out garage and household material, Shirva, 6th April 2019. Only Shetland record. Characterised by very faintly verruculose ascospores.

Peziza vesiculosa. Blistered cup, common dung cup. On horse and pony dung, Barkland, 17th June 2006. Only Shetland record.

Pyronemataceae

Aleuria aurantia. Orange peel fungus. Two records: *ca.* 50, dry disturbed ground, Vaadal gully, 9th October 1989, and small cluster on turned-over bare soil, Brekkawalls, 28th September 2020.

Cheilymenia raripila. Reported by RWGD, undated, on rabbit pellets.

Neottiella vivida. Occasional. In small colonies amongst rocks, soil and sparse vegetation, Lower Station and Ward Hill.

Scutellinia olivascens. Little skullcap. Rare adventive. Several strong groups, wet clay soil, footpath, back of Houll, 28th October 2015. Only Shetland record. Vector for spores could be birdwatchers' boots.

Tricharina gilva. Small cluster, ash-rich soil, The Haa, 11th September 2016.

Uncertain position

Coprotus aurora. Reported by RWGD, undated, on rabbit pellets. Only Shetland record.

Coprotus sexdecimsporus. Reported by RWGD, undated, on sheep dung.

Rhytismatales

Rhytismataceae

Lophodermium juniperinum. Juniper split. Reported by RWGD, undated, on juniper. Only Shetland record.

Rhytisma salicinum. Willow tarspot. Abundant on *S. herbacea* leaves, Ward Hill, late June - July. Not found yet on *S. repens*.

SORDARIOMYCETES

Hypocreales

Calcarisporiaceae

Calcarisporium arbuscula. On *Agaricus cupreobrunneus*, below Burkle, 23rd August 2018. Only Shetland record. Endophyte of discomycetes, occasionally on agarics. An anamorphic taxon lacking evidence of a sexual stage.

Clavicipitaceae

Claviceps purpurea. Ergot. Common to abundant on sweet vernal grass (*Anthoxanthum odoratum*) capitula, particularly roadsides (e.g. Gilsetter roadside), occasional on mat-grass and infrequent on perennial rye-grass (*Lolium perenne*); records only as sclerotia, these evident first in mid summer, well-developed by late August - September.

Cordyceps gracilis. Rare or overlooked. Ward Hill, 3rd July 2010.

Cordyceps militaris. On buried caterpillar, September 1985.

Nectriaceae

Fusarium sporotrichioides. Fusarium head blight. On snowy waxcap *Cuphophyllus virgineus* Schoolton, 19th September 2016. An anamorphic taxon lacking known sexual stage.

Magnaporthales

Magnaporthaceae

Gaeumannomyces graminis. Take-all. Dark brown structures on cultivated oat (*Avena sativa*) heads, Upper

Leogh, 13th December 2017. This would be *G. graminis* var. *avenae* (Turner), according to Dennis (1960).

Phyllachorales
Phyllachoraceae
Phyllachora graminis. Common grass tar spot, black leaf spot of grasses. Frequent on couch grass (*Agropyron repens*) leaves, roadside, Leogh, 19th June 2020.
Phyllachora sylvatica. Fescue black leaf spot, fescue tar spot. Frequent on leaves of red fescue in semi-improved and ungrazed rough grassland, from late June.

Sordariales
Lasiosphaeriaceae
Schizothecium conicum. On sheep droppings, September 1985.
Schizothecium vesticola. On sheep droppings, September 1985.

Sordariaceae
Sordaria minima. On rabbit droppings, September 1985.

Xylariales
Amphisphaeriaceae
Physalospora empetri. Reported by RWGD, undated, on dead attached twigs of crowberry. Only Shetland record. But highly likely to occur elsewhere in the archipelago.

Diatrypaceae
Diatrypella favacea. Birch blackhead. Casual introduction. Abundant fruiting bodies on silver birch (*Betula pendula*) trunk, Shirva, 15th October 2013. Imported from Norway on wood destined for carpentry and destroyed.

DOTHIDEOMYCETES
Hysteriales
Hysteriaceae
Gloniopsis praelonga. On *Salix* bark (an atypical host), Plantation, 25th August 2016 (Brian Coppins). Often misidentified as the lichen *Graphina ruiziana* but the latter has iodine-positive purple brown spores whereas *G. praelonga* has iodine-negative spores.

Pleosporales
Didymellaceae
Epicoccum purpurascens. On perennial rye-grass, Schoolton, 11th September 2006. Probably common but overlooked. An anamorphic taxon with no known sexual stage.

Pithomyces chartarum. Lamb's ear. Isolated cases on sheep, Hill Grazings. There is possibly a causal relationship with parched grasses in dry summers, as in 2018 (according to Iain Stout, crofter). Only Shetland record. An anamorphic taxon with no known sexual stage.

Mycosphaerellaceae
Ramularia pratensis. Reported by RWGD, undated, on common sorrel (*Rumex acetosa*). Only Shetland record. Causes round or elliptic pale brown-purple to red-bordered lesions on *Rumex* species. An anamorphic taxon.
Septoria scabiosicola. Rust spots on leaf of devil's bit scabious, below Stackhoull Stores, 22nd August 2015. An anamorphic taxon.

Phaeotrichaceae
Trichodelitschia bisporula. Reported by RWGD, undated, on rabbit pellets. Only Shetland record.

Pleosporaceae
Dilophospora alopecuri. Twist, plumed spore disease of cereals. On Yorkshire fog leaves, Schoolton, 19th September 2016. An anamorphic taxon.

Uncertain position: Hyphales ("Hyphomycetes")
Endoconospora cerastii. Reported by RWGD, undated, on mouse-ear chickweed (*Cerastium fontanum*); only Shetland record. An anamorphic taxon.

5. True moulds
MUCOROMYCETES
Mucorales
Pilobolaceae
Pilobolus crystallinus. Dung cannon. Reported by RWGD, with no further detail.

Entomophthorales
Entomophthoraceae
Conidiobolus coronatus. Relatively common in gardens; characterised by classic moribund Diptera at apex of plants; summer. Only Shetland records.

B. "FAKE FUNGI"
A group of organisms previously considered to be fungi and studied as such by mycologists.

1. Chromista
OOMYCOTA
Peronosporales
Peronosporaceae
Peronospora rumicis. Sorrel downy mildew. Reported by RWGD with no further detail. A downy mildew on common sorrel and sheep's sorrel (*Rumex acetosella*).

Phytophthora infestans. Potato blight. Common, on potato (*Solanum tuberosum*). A persistent pest of potato rigs, particularly prevalent in damp hollows such as Houll Cuppas and during damp summers.

Plasmopara densa. Downy mildew. On eyebright (*Euphrasia* sp.), Buness, 13th August 2018.

Plasmodiophorales
Plasmodiophoraceae
Plasmodiophora brassicae. Club root, finger-and-toe. Occasional in gardens on brassicas. Also reported by RWGD with no further detail.

2. Protista (slime moulds and others)
Stemonitidea
Didymiidae

Mucilago crustacea. Dog sick slime mould. Common and widespread, on ungrazed rough grassland, particularly roadsides, in-bye, end of summer; extreme dates 11th August and 10th October; short-lived, degrading within a few days. Only Shetland records.

Physarida

Physaridae

Fuligo septica. Scrambled egg slime, flowers of tan. Small group, north slope of Utra Brae, 7th May 2016. First for Northern Isles.

DISCUSSION

From the 52 taxa appearing in Watling & Riddiford (1986), the tally has grown to 260, nine of which are additional intraspecific variants. Several further entities remain provisional until fresh mature material becomes available. Watling (1992) listed 989 taxa for Shetland, with a further 62 unconfirmed or not identified to a known species. The Fair Isle totals are only a quarter of that number and, notably, a number of common Shetland fungi are absent. The lower proportion and absentees can be attributed to several factors: much smaller land area; more restricted range of substrates and habitats, not least the absence of trees; and, perhaps, some imbalance in the intensity of collecting between the two areas. Most importantly, the geographical isolation of an island 34 km from the nearest land mass (the southern tip of Shetland Mainland) will have its effect. This has been illustrated for two other well-worked taxonomic groups – vascular plants and spiders. Fair Isle shares only 40% of the Shetland flora (Quinteros Peñafiel *et al*., 2017; Scott & Palmer, 1987) and there are some notable absentees. The spider diversity is more complete but still 30% short of the full Shetland fauna (Milner, 2006; Riddiford, unpublished data).

Lower diversity does not equate to diminished biodiversity. The current list includes four taxa that are first notifications for the British Isles and three for the second time. A further seven are conservation listed and more than 60 are first citations for Shetland. Amongst the fungi is an *Entoloma* sp. which could yet prove to be an undescribed species. The CHEGD grassland fungi are notably represented. This is a group endangered throughout Europe as their unimproved habitat is lost to modern agriculture (Arnolds, 1989; Eriksson *et al*., 1995; Lovegrove *et al*., 1995). There is a strong Nordic theme to some exceptional montane taxa, particularly associated with *Salix herbacea*. For its size (768 ha), Fair Isle registers an impressively rich fungus "flora" of regional, national and international importance.

ACKNOWLEDGEMENTS

It is pleasing to acknowledge the high level of interest amongst Fair Islanders with special mention of Elizabeth Riddiford, Rachel Challoner, Luca Rotolo, the Thomson and Parnaby families. Alison Murfitt made an important contribution in a three-day visit in 2011. The two reviewers are thanked for their input to the final draft. The authors dedicate this paper to inspirational Shetland Naturalist, the late Bobby Tulloch, who pioneered the study of Shetland fungi including Fair Isle as well as warmly hosting RW and helping him to reach otherwise difficult localities during his many trips to Shetland and its islands.

REFERENCES

Arnolds, E. (1986). Notes on Hygrophoraceae – VIII. Taxonomic and nomenclatural notes on some taxa of *Hygrocybe*. *Persoonia* 13, 137-160.

Arnolds, E. (1989). The influence of increased fertilization on the macrofungi of a sheep meadow in Drenthe, the Netherlands. *Opera Botanica* 100, 7-21.

Dennis, R.W.G. (1960). *British Cup Fungi and their Allies*. Ray Society, London.

Dennis, R.W.G. (1972). Fungi of the Northern Isles. *Kew Bulletin* 26, 427-432. https://doi.org/10.2307/4120305

Dennis, R.W.G. & Gray, E. (1954). A first list of the fungi of Zetland (Shetland). *Transactions of the Botanical Society of Edinburgh* 36, 205-223. https://doi.org/10.1080/13594865409441610

Eriksson, A., Eriksson, O. & Berglund, H. (1995). Species abundance patterns of plants in Swedish semi-natural pastures. *Ecography* 18, 310-317. https://doi.org/10.1111/j.1600-0587.1995.tb00133.x

Hora, F.B. (1957). The genus *Panaeolus* in Britain. *The Naturalist* 1957, 77-88.

Kühner, R. (1975). Agaricales de la Zone Alpine: genre *Russula* Pers. ex S. F. Gray. *Bulletin de la Société mycologique de France* 91, 313-390.

Legon, N.W., Henrici, A., Roberts, P.J., Spooner, B.M. & Watling, R. (2005). *Checklist of the British & Irish Basidiomycota*. Royal Botanic Garden, Kew.

Lovegrove, R., Shrubb, M. & Williams, I. (1995). *Silent Fields*. RSPB Wales.

Milner, J.E.D. (2006). An annotated list of Shetland spiders and pseudoscorpions, including new records up to 2005. *Shetland Naturalist* 2(3), 83-96.

Moeller, F.H. (1945). *Fungi of the Faeroes. Part 1. Basidiomycetes*. Munksgaard, Copenhagen.

Murfitt, A. (2011). *Grassland Fungi Survey, September 2011*. BTCV/NTS draft report, unpublished.

Price, S. (2017). Lichens and lichenicolous fungi of Fair Isle: an annotated checklist. *Fair Isle Bird Observatory Report* 68, 71-187.

Orton, P.D. (1960). New check list of British agarics and boleti. *Transactions of the British Mycological Society* 43(2), 159-439. https://doi.org/10.1016/S0007-1536(60)80065-4

Quinteros Peñafiel, C.V., Riddiford, N.J. & Twyford, A.D. (2017). A floristic survey of Fair Isle. *New Journal of Botany* 7, 101-111. https://doi.org/10.1080/20423489.2017.1393191

Riddiford, N.J., Watling, R. & Murfitt, A. (2020). *Grassland Fungi*. FIBO, Fair Isle. http://www.fairislebirdobs.co.uk/grassland_fungi.html

Riddiford, N.J. & Watling, R. (2020a). RSPB Management News: Response of grassland fungi to an agricultural change. *British Wildlife* 31, 412-413.

Riddiford, N.J. & Watling, R. (2020b). *Response of Grassland Fungi to an Agricultural Change*. FIBO, Fair Isle. http://www.fairislebirdobs.co.uk/grassland_fungi.html
Rotheroe, M., Newton, A., Evans, S. & Feehan, J. (1996). Waxcap-grassland survey. *The Mycologist* 10, 23-25. https://doi.org/10.1016/S0269-915X(96)80046-2
Scott, W. & Palmer, R. (1987). *The Flowering Plants and Ferns of the Shetland Islands*. The Shetland Times Ltd., Lerwick, Shetland.
Watling, R. (1992). *The Fungus Flora of Shetland*. Royal Botanic Garden, Edinburgh.
Watling, R., King, R. & Riddiford, N.J. (2001). New and interesting records of fungi from Shetland. *Botanical Journal of Scotland* 53(1), 57-64. https://doi.org/10.1080/03746600108684955
Watling, R. & Riddiford, N.J. (1986). Fair Isle fungi list, 1985. *FIBO Report* 38, 83-84.
Watling, R. & Riddiford, N.J. (1987). Additions to the Fair Isle fungi list, 1986. *FIBO Report* 39, 65.

APPENDIX

Ordnance Survey grid references for locations mentioned in the text

Fair Isle belongs to vice-county 112 (Shetland) for recording purposes.

Airstrip HZ211721
Back of Houll HZ204707
Barkland HZ208711
Bird Observatory HZ222723
Boini Mire HZ205706
Breckawalls HZ207709
Breed Piece HZ210723
Bullock Holes HZ219727
Buness HZ2272
Burkle HZ204702
Byerwall HZ2171
Chatham's Land HZ208710
Ditfield HZ221721
Eas Brecks HZ2172
Field HZ21117 71524
Furse HZ224732
Gilsetter HZ214718
Grand Canyon HZ209723
Hesti Geo HZ198702
Hill Grazings HZ27
Hjukni Geo HZ202711
Hoini HZ203714
Houll Cuppas HZ205706
Kenaby HZ207702
Kirk HZ206706
Kirki Geo HZ200698
Leogh HZ201702
Linni Geo HZ199706
Lower Station HZ211731
Lower Stoneybrek HZ20547092
Malcolm's Head HZ198704
Mavers Geo HZ222723
Meoness HZ205697
Midway HZ202705
North Grind HZ212717
North Haven HZ224725
North Light HZ221740
North Naaversgill HZ203726
Plantation HZ212717
Pund HZ206714
Rippack HZ20647064
Quoy HZ204704
School HZ207709
Schoolton HZ204704
Setter HZ209715
Shalstane HZ197699
Shirva HZ202709
South Haven HZ224724
South Light HZ197688
South Light Brae HZ197697
Springfield HZ207699
Stackhoull Stores HZ204708
Stonybreck HZ205709
Sukka Mire HZ208721
Swarts Geo HZ209702
Swey HZ213734
Taing HZ208709
Tarryfield HZ208718
The Haa HZ202700
Upper Leogh HZ201702
Utra Brae HZ198699
Vaadal Plantation HZ212717
Vaila's Trees HZ204708
Valsbrough HZ2070
Vatstrass HZ217721
Ward Hill HZ208734
Ward Hill north slope HZ20827343
Wester Lother HZ211738
Ward Hill summit HZ20847341
Wirvie HZ217736

The Glasgow Naturalist (2021) Volume 27, Part 3, 42-47 https://doi.org/10.37208/tgn27323

Freshwater aquatic invertebrates on the Isle of May, Scotland

C.R. Macadam

Buglife Scotland, Balallan House, 24 Allan Park, Stirling FK8 2QG

E-mail: craig.macadam@buglife.org.uk

ABSTRACT

The invertebrate fauna of freshwater habitats on the Isle of May, Scotland was investigated and compared with the results from surveys undertaken in 1958. Overall, the freshwater invertebrate fauna appears to be diminished. However, several species were recorded as new to the Isle of May. Although the reasons for the apparent decline in freshwater invertebrates on the island are unclear, an increase in the temporary nature of the habitats due to climate warming may be a contributing factor.

INTRODUCTION

The Isle of May is located approximately 8 km south-east of the mainland at Anstruther in Fife, Scotland, lying roughly north-west to south-east in the mouth of the Firth of Forth. The island is 1.8 km long by 0.5 km wide and is 57 ha in area. The east side of the island is characterised by a low-lying rocky coastline whilst the west side is dominated by high cliffs. The island is currently owned and managed by NatureScot (formerly known as Scottish Natural Heritage). Staff from NatureScot stay on the island every summer along with several research students to manage the island and conduct scientific research on nesting seabirds.

The Isle of May is renowned for its internationally important populations of breeding seabirds and grey seals (*Halichoerus grypus*) and its sub-tidal reefs, as well as being nationally important for its population of wintering waders (Pickett & Luurtsema, 2014). The island is heavily protected because of this and is a National Nature Reserve as well as being in a European Special Protection area for its breeding seabirds, and a Special Area of Conservation for seals, and it lies in the Forth Islands Special Protection Area. A bird observatory opened on the island in 1934, and scientific studies on several species of seabirds that nest on the island, including puffin (*Fratercula arctica*), kittiwake (*Rissa tridactyla*), shag (*Phalacrocorax aristotelis*) and eider duck (*Somateria mollissima*), began in 1966 (Pickett & Luurtsema, 2014).

The earliest record of aquatic invertebrates on the Isle of May is of the brackish-water amphipod *Gammarus duebeni* and the seed shrimp *Heterocypris incongruens*, which were recorded in pools on the island in the 1890s (Scott, 1906). Invertebrates are, however, under-recorded on the Isle of May and few recent surveys have been undertaken. Eggeling (1960) summarised the records of species, including those from freshwater habitats, from the Isle of May. These include adult records of the dragonflies *Sympetrum fonscolombii* and *Aeshna juncea* reported by Evans (1912) and Eggeling (1956, 1957), and records of adult caddisflies attracted to the lamp of the lighthouses on the island (Evans 1915a,b). These species are all strong flyers and the individuals reported almost certainly originated from the mainland, as suitable habitat for their juvenile stages is absent on the Isle of May. Maitland (1967) provided the first comprehensive investigation of the aquatic fauna of the Isle of May following surveys undertaken in 1958. In August 2012 a team of four individuals from Buglife – The Invertebrate Conservation Trust spent three days (1st–3rd August) on the Isle of May to undertake surveys of invertebrates in various habitats present on the island. This paper describes the results of surveys of freshwater habitats on the island.

METHODS

Maitland (1967) identified 26 freshwater sites separated into six areas on the island (Fig. 1; Table 1). Several water bodies reported by Maitland (1967) were not found (Table 1), or were devoid of water (Fig. 1: stations c, q and r), possibly as a result of the extended spell of dry, warm weather that preceded the surveys in 2012. In addition, the location of the two springs identified by Maitland (1967) (Fig. 1: stations t and u) were located though they were not flowing at the time of these surveys. None of the wells on the island (Fig. 1: stations v to z) were sampled, to prevent disturbance of the water supply. However, a further two small ponds were located during this study in the area known as West Braes (Fig. 1):

Station aa. West Braes Pond 1 (9.8 m x 7.9 m; 0.2-0.3 m deep) is a located in the area known as West Braes, overlooking Fluke Street and the Loch. The southern bank of this pond is comprised of a rock face approximately 1 m high and it is here that the water is at its deepest (Fig. 2). The water of this pond was clear at the time of sampling and the bed is made up of pockets of soft sediments and some patches of shoreweed (*Littorella uniflora*). There are also small clumps of small sweet grass (*Glyceria declinata*) and common water starwort (*Callitriche stagnalis*) present.

Fig. 1. Outline map of the Isle of May, Scotland showing the location of the water bodies mentioned in the text. Adapted from Maitland (1967).

Fig. 2. West Braes Pond 1 (aa), Isle of May, Scotland. (Photo: C.R. Macadam)

Code	Maitland Name	Current Name	Grid Reference	Sampled in this study
a	The Loch	The Loch	NT6564599206	Yes
b	North Plateau Pool I		Not found	No
c	North Plateau Pool II		NT6524599480	No
d	North Plateau Pool III	Three Tarn Nick Pond 1	NT6538199477	Yes
e	North Plateau Pool IV	Three Tarn Nick Pond 2	NT6536699470	Yes
f	North Plateau Pool V	Three Tarn Nick Pond 3	NT6535199464	Yes
g	North Plateau Pool VI	Three Tarn Nick Pond 4	NT6533899458	Yes
h	North Plateau Pool VII	Three Tarn Nick Pond 5	Not found	No
i	South Plateau Pool I	High Tarn Pond 2	NT6557799169	Yes
j	South Plateau Pool II	High Tarn Pond 1	NT6554499121	Yes
k	South Plateau Pool III	Cornerstone Pond 4	NT6572899011	Yes
l	South Plateau Pool IV	Cornerstone Pond 3	NT6574899015	Yes
m	South Plateau Pool V	Cornerstone Pond 2	NT6575398985	Yes
n	South Plateau Pool VI	Cornerstone Pond 1	NT6577199005	Yes
o	East Pool I		Not found	No
p	East Pool II		Not found	No
q	East Pool III		NT6589699257	No
r	East Pool IV		NT6593999220	No
s	East Pool V		Not found	No
t	Spring I	Spring I	NT6548099558	No
u	Spring II	Spring II	NT6581399006	No
v	Well I	St Andrew’s Well	NT6537599592	No
w	Well II	St John’s Well	NT6585899107	No
x	Well III	Pilgrims Well	NT6590998880	No
y	Well IV	Ladies Well	NT6603498827	No
z	Well V	Sheep Well	NT6538799363	No
aa		West Braes Pond 1	NT6567599278	Yes
bb		West Braes Pond 2	NT6565999255	Yes

Table 1. Freshwater habitats on the Isle of May, Scotland.

Station bb. West Braes Pond 2 (6.6 m x 5.3 m; 0.1 m deep) is a roughly triangular shaped, shallow pond located to the south west of West Braes Pond 1. At the time of sampling the water was clear, and the bed was comprised of fine silt. There are numerous docks (*Rumex* sp.) growing in, and around the edge of the pond, together with patches of ivy-leaved crowfoot (*Ranunculus hederaceus*) and common water starwort.

Access to some areas of the island was restricted due to nesting birds and scientific studies being undertaken. In particular the island of Rona that lies to the north of the main island was off limits due to a long-term research project. Similarly, sampling was not possible at pond c at NT6524599480 due to roosting gulls (*Larus* sp.).

The methods used during this survey were similar to those of Maitland (1967). A standard Freshwater Biological Association (FBA) pattern hand-net was used to collect invertebrates from the substrate and submerged and emergent vegetation. Standardised monitoring using the methods developed for the National Pond Survey (Pond Action, 1998) was not possible due to the shallowness of the water and soft sediments in some of these ponds. Instead, the sediments were lightly disturbed, and the net swept through the water to collect dislodged invertebrates. The time taken for sampling varied between locations, depending on the size of the water body and the complexity of the habitat, but was generally within one to three minutes. The resulting sample of invertebrates, mixed with plant material, mineral particles and detritus, was placed in a large white tray and sorted on the bankside. Specimens that could be identified on site were released. For specimens that needed further examination they were placed in tubes with 70% isopropanol and were labelled with the location, collection method and date. Specimens were identified to family, genus or species at a later date away from the island by examination under a stereomicroscope with reference to appropriate taxonomic books and keys. In some cases, it was impossible to identify damaged or immature specimens and these were recorded at the most appropriate taxonomic precision.

RESULTS

A total of 17 freshwater invertebrate taxa were recorded during these surveys (Table 2). This was considerably fewer than the 29 species reported by Maitland (1967). In particular, this study recorded only three species of crustacean and five species of water beetle, whereas the previous survey recorded six and eight species respectively. Nevertheless, several novel species were recorded during the current study. The water flea *Daphnia magna* was collected from five ponds and the water beetle *Hydroporus planus* was recorded from four ponds. The most novel species recorded were aquatic bugs (Hemiptera), with *Corixa punctata*, *Callicorixa wollastoni*, and *Sigara stagnalis* each being recorded on one occasion only. Finally, the New Zealand mud snail (*Potamopyrgus antipodarum*) was recorded new to the island from West Braes Pond 1 (aa). This is a non-native species, which is known from brackish water, but which has successfully colonised a range of freshwater habitats throughout Great Britain (Macan, 1977).

Midge larvae (family Chironomidae) were recorded from six ponds and worms (Oligochaeta) from three ponds. However, these were not identified further, so several species may be present. The flatworm *Procerodes littoralis* was re-recorded from the Loch.

A single species of freshwater shrimp (Amphipoda) was recorded during the surveys. *Gammarus duebeni* is a brackish water species, which is typically found on rocky shores in pools near to high water that have a freshwater influence (Gledhill *et al.*, 1993). Two species of water flea (Cladocera) were recorded during the freshwater surveys. *Daphnia magna* is known to be tolerant of brackish conditions and is often found in rock pools (Hanski & Ranta, 1983), while *D. obtusa* favours nutrient-enriched pools, particularly those frequented by wildfowl (Fryer, 1985).

Five species of very commonly recorded water beetles were recorded during this study, the most commonly encountered being *Hydroporus planus*, which is new to the island since 1958. Four species of water beetle recorded in 1958 were not re-found.

The aquatic bugs were the most speciose order, with six species all from the family Corixidae recorded. Across the two studies this brings the number of aquatic bug species recorded from the island to nine.

DISCUSSION

This study has provided an update on the freshwater invertebrate fauna of the Isle of May. Since 1958 the freshwater invertebrate fauna of the Isle of May appears to have diminished considerably. Of the 29 taxa recorded by Maitland (1967) only 12 were recorded in the present study. The reason for this reduction is not clear. However, the temporary nature of many of the water bodies and the limited colonisation opportunities available are probably key factors. In addition, the surveys undertaken were limited by the amount of time spent on the island as only one visit was made for three days in early August. Being present at one specific time of the year will ultimately miss recording species that are only found either before or after this period of time. The previous study was undertaken in late June and it is possible that the species composition was influenced by the timing of the surveys.

Despite the distance from the mainland, six species were recorded as new to the island in this study. These species can be separated into two categories based on their possible colonisation mechanism: those that probably arrived naturally by flying from the mainland (*Corixa punctata*, *Callicorixa wollastoni*, *Sigara stagnalis*, and *Hydroporus planus*); and those that probably arrived either as eggs or adults amongst the plumage of bird species visiting the island (*Daphnia magna* and *Potamopyrgus antipodarum*). Several authors have demonstrated that aquatic invertebrates can travel long distances in the latter fashion, potentially allowing the

Class/Order	Family	Species	a	b	d	e	f	g	h	i	j	k	l	m	n	o	r	s	t	u	w	x	aa	bb
Amphipoda	Gammaridae	*Gammarus duebeni*	●														✖				✖	✖	○	○
Annelida	Oligochaeta	-	●	✖					✖		●						✖	✖	✖	✖				
Arachnida	Hydracarina	-												✖										
Bivalvia	Sphaeriidae	*Pisidium casertanum*																						
Cladocera	Daphniidae	*Daphnia magna*								○	○				○								○	○
Cladocera	Daphniidae	*Daphnia obtusa*								○	✖	✖	✖	✖										
Cladocera	Eurycercidae	*Chydorus sphaericus*										✖	✖	✖	✖	✖	✖		✖					
Cladocera	Macrothricidae	*Macrothrix hirsuticornis*		✖										✖	✖									
Cyclopoida	Cyclopidae	*Cyclops strenuus*	✖	✖								✖	✖	✖	✖	✖	✖	✖	✖	✖		✖		
Coleoptera	Dytiscidae	*Agabus bipustulatus*	✖	✖					✖		✖	✖	✖	✖		✖	✖	✖	✖	✖				
Coleoptera	Dytiscidae	*Agabus nebulosus*							✖		○		○	○										
Coleoptera	Dytiscidae	*Colymbetes fuscus*										●		✖										
Coleoptera	Dytiscidae	*Hydroporus planus*				○	○							○	○									
Coleoptera	Dytiscidae	*Hydroporus pubescens*	✖	✖	○		○		✖		✖	●	✖	✖		✖	✖	✖	✖	✖				
Coleoptera	Helophoridae	*Helophorus flavipes*											✖				✖							
Coleoptera	Hydrophilidae	*Anacaena limbata*													✖	✖								
Coleoptera	Hydrophilidae	*Hydrobius fuscipes*					○									✖								
Coleoptera	Hydrophilidae	*Laccobius bipunctatus*														✖								
Diptera	Chironomidae	-		✖				○	✖	○	●	✖	✖	●	●	✖	✖	✖	✖	✖				○
Gastropoda	Hydrobiidae	*Potamopyrgus antipodarum*																					○	
Gastropoda	Lymnaeidae	*Galba truncatula*																	✖					
Hemiptera	Corixidae	*Arctocorisa germari*							✖															
Hemiptera	Corixidae	*Callicorixa praeusta*			○				✖		●	✖	✖		✖									
Hemiptera	Corixidae	*Callicorixa wollastoni*			○																			
Hemiptera	Corixidae	*Corixa punctata*												○										
Hemiptera	Corixidae	*Sigara falleni*							✖															
Hemiptera	Corixidae	*Sigara lateralis*			○					○	✖		✖	●									○	○
Hemiptera	Corixidae	*Sigara nigrolineata*							✖	○	✖			✖		✖	✖							
Hemiptera	Corixidae	*Sigara stagnalis*			○																			
Hemiptera	Notonectidae	*Notonecta glauca*							✖					✖										
Nematomorpha	Gordiidae	*Gordius* sp.																✖						
Ostracoda	Cyprididae	*Heterocypris incongruens*		✖								✖				✖								
Platyhelminthes	Dalyelliidae	*Dalyellia* sp.										✖												
Platyhelminthes	Procerodidae	*Procerodes littoralis*	●																					
Trichoptera	Phryganeidae	-												✖										

Table 2. Taxa recorded from the Isle of May, Scotland. ✖ = recorded by Maitland (1967) only; ○ = recorded in this study only; ● = recorded in both studies.

colonisation of remote locations (e.g. Figuerola *et al.*, 2005; Green & Figuerola, 2005; Wesselingh *et al.*, 1999).

Although Maitland (1967) believed that the springs on the island were permanent, at the time of this study these springs were not flowing. The majority of other freshwater habitats on the island are also temporary in nature, with the associated invertebrate fauna either specially adapted to survive periods with no water (e.g. *Daphnia* spp. through diapause), or being capable of finding an alternative habitat (e.g. *Colymbetes fuscus* and *Corixa punctata* through having a long adult life and being able to fly). Temporary water bodies can be home to unique assemblages of aquatic invertebrates (Collinson *et al.*, 1995). However, on the Isle of May nutrient enrichment from bird faeces likely limits the potential of the various ponds.

More permanent water bodies are indicated by species which do not exhibit these characteristics. The only examples in the current study is the flatworm *Procerodes littoralis*, which was recorded from the Loch (a) and the freshwater shrimp *Gammarus duebeni*, which was recorded from the Loch (a), and West Braes Pond 1 (aa) and 2 (bb).

The annual average air temperature in the east of Scotland has increased by *ca.* 1°C over the period 1961 to 2004 (Barnett, 2006). Whilst average precipitation totals have also increased, this is mostly in the winter months with little or no change during the spring or summer (Barnett, 2006). This will likely have led to accelerated drying of temporary freshwater habitats on the Isle of May, putting further pressure on these habitats and the flora and fauna occupying them (Ewald, 2008).

ACKNOWLEDGEMENTS
The author is grateful to David Pickett and the rest of the NatureScot NNR team for facilitating access to the island, arranging accommodation during this study, and providing much information on the natural history of the Isle of May. Thanks are also due to Professor Garth Foster and Dr Hannah Robson who provided identification assistance for aquatic Coleoptera and Cladocera respectively.

REFERENCES
Barnett, C., Hossell, J., Perry, M., Procter, C. & Hughes, G. (2006). *A Handbook of Climate Trends across Scotland*. SNIFFER project CC03, Scotland & Northern Ireland Forum for Environmental Research.
Collinson, N.H., Biggs, J., Corfield, A., Hodson, M.J., Walker, D., Whitfield, M. & Williams, P.J. (1995). Temporary and permanent ponds: an assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities. *Biological Conservation* 74, 125-133. https://doi.org/10.1016/0006-3207(95)00021-U
Eggeling, W.J. (1956). Dragonflies recorded from the Isle of May. *Scottish Naturalist* 68, 173.
Eggeling, W.J. (1957). Dragonflies recorded from the Isle of May. *Scottish Naturalist* 69, 117.
Eggeling, W.J. (1960). *The Isle of May*. Oliver & Boyd, Edinburgh.
Evans, W. (1912). On the occurrence of *Sympetrum fonscolombii* (Selys) – A dragon-fly new to the Scottish list – in the Forth Area. *Scottish Naturalist* 1, 12-14.
Evans, W. (1915a). Lepidoptera (moths) and other insects at Scottish lighthouses, chiefly in the Forth area. *Scottish Naturalist* 37, 8-12.
Evans, W. (1915b). Lepidoptera (moths) and other insects at Scottish lighthouses, chiefly in the Forth area. *Scottish Naturalist* 40, 84-88.
Ewald, N.C. (2008). *The Impact of Climate Change on Temporary Pond Macroinvertebrate Communities*. Ph.D. thesis, University of Sussex.
Figuerola, J., Green, A.J. & Michot, T.C. (2005). Invertebrate eggs can fly: evidence of waterfowl mediated gene-flow in aquatic invertebrates. *American Naturalist* 165, 274-280. https://doi.org/10.1086/427092
Fryer, G. (1985). The ecology and distribution of the genus *Daphnia* (Crustacea: Cladocera) in restricted areas: the pattern in Yorkshire. *Journal of Natural History* 19, 97-128. https://doi.org/10.1080/00222938500770051
Gledhill, T., Sutcliffe, D.W. & Williams, W.D. (1993). *British Freshwater Crustacea Malacostraca: a Key with Ecological Notes*. Scientific Publications No. 52. Freshwater Biological Association, Ambleside.
Green, A.J. & Figuerola, J. (2005). Recent advances in the study of long-distance dispersal of aquatic invertebrates via birds. *Diversity and Distributions* 11, 149-156. https://doi.org/10.1111/j.1366-9516.2005.00147.x
Hanski, I. & Ranta, E. (1983). Coexistence in a patchy environment: three species of *Daphnia* in rock pools. *Journal of Animal Ecology* 52, 263-279. https://doi.org/10.2307/4599
Macan, T.T. (1977). *A Key to the British Fresh- and Brackish-Water Gastropods, with Notes on their Ecology*. Scientific Publications No. 13. Freshwater Biological Association, Ambleside.
Maitland, P.S. (1967). The aquatic fauna of the Isle of May, Fife, Scotland. *Transactions of the Dumfries & Galloway Natural History & Antiquarian Society* 44, 16-29.
Pickett, D. & Luurtsema, S. (2014). *The Story of the Isle of May National Nature Reserve*. (2nd edition). Scottish Natural Heritage, Inverness.
Pond Action (2002). *A Guide to Monitoring the Ecological Quality of Ponds and Canals Using PSYM*. Pond Action, Oxford.
Scott, T. (1906). A catalogue of land, fresh-water, and marine Crustacea found in the basin of the River Forth and its estuary. *Proceedings of the Royal Physical Society of Edinburgh* 16, 97-190, 267-386. https://doi.org/10.5962/bhl.title.53706
Wesselingh, F.P., Cadée, G.C. & Renema, W. (1999). Flying high: on the airborne dispersal of aquatic organisms as illustrated by the distribution histories

of the gastropod genera *Tryonia* and *Planorbarius*. *Geologie en Mijnbouw* 78, 165-174. https://doi.org/10.1023/A:1003766516646

The Glasgow Naturalist (2021) Volume 27, Part 3, 48-67 https://doi.org/10.37208/tgn27318

Monitoring Scotland's transitional water fish communities under the EU Water Framework Directive

M. O'Reilly[1], J. Boyle, S. Nowacki, M. Elliott & R. Foster

Scottish Environment Protection Agency, Angus Smith Building, 6 Parklands Avenue, Eurocentral, Holytown, North Lanarkshire ML1 4WQ

[1]E-mail: myles.oreilly@sepa.org.uk

ABSTRACT

The history of monitoring transitional water fish in Scotland is briefly outlined. The requirements of the EU Water Framework Directive are explained and how this applies to the monitoring of transitional water fish communities in Scotland is described. The development of a monitoring programme for Scotland is outlined, including sampling methods and strategies. Six transitional waters were selected as representative for Scotland covering three different types of transitional water. A multi-metric tool, the Transitional Water Fish Classification Index was used to assess the ecological status of the fish communities in these waters and the operation of the different metrics and the creation of appropriate reference conditions is explained. The assessment tool was applied to survey data from 2005 to 2018, although only the more recent data fully met the tool requirements. The species composition and abundances in the respective transitional waters were compared. The fully valid surveys were all classed as of Good or High status, indicating the fish communities in all the representative transitional waters appeared to be in good ecological health. The efficacy of the different metrics is considered and some issues with Metric 2, enumerating migratory species, are discussed at length. A new multi-metric tool, the Estuarine Multi-metric Fish Index, is briefly discussed and its introduction for the assessments in Scotland is recommended.

Supplementary Files are available at:
https://www.glasgownaturalhistory.org.uk/gn27_3/O'Reilly_etal_supplementary_files.pdf

INTRODUCTION

Transitional waters are bodies of surface water that are partly saline, such as estuaries and reduced salinity sea lochs. They are very important habitats for fish communities, including many species of commercial and conservation importance, which use them as nurseries, feeding and refuge areas, and migration routes (Elliott & Hemingway, 2002). Estuarine fish communities may act as sentinels of ecological change and assessing their status is a key aspect of environmental monitoring (Whitfield & Elliott, 2002). While much attention has been paid to the studies of fisheries in Scotland's fresh and marine waters, rather less effort has gone into investigations of the fish communities in transitional waters. The exception is for the estuaries of the Rivers Clyde and Forth, both of which have heavily industrialised hinterlands with consequent impacts upon their estuaries. Monitoring of the fish communities in these waters was initiated by the Clyde and Forth River Purification Boards (CRPB & FRPB) in the late 1970s in response to water pollution concerns. Both estuaries suffered serious effects from industrial and municipal discharges, as well as impacts from diffuse pollution and land reclamation (for Clyde Estuary see Mackay *et al*., 1978; Hammerton, 1986, 1997; Haig, 1986; and for Forth Estuary see Elliott & Griffiths, 1986, 1987; McLusky, 1987; Griffiths, 1987; Leatherland, 1987).

The monitoring in the Clyde and Forth Estuaries aimed to gauge the impact on the estuarine fish populations and measure recovery following implementation of the Control of Pollution Act (1974). Fish sampling was carried out quarterly, mostly using beam trawls or Agassiz trawls. In the Clyde Estuary the trawling surveys commenced in 1978 at four sites in the lower estuary, one at Pillar Bank, and three between the River Leven and Bowling (Henderson & Hamilton, 1986). In the Forth Estuary the trawling surveys commenced in 1977 with five sites in the lower estuary (Longannet, Tancred, Bo'ness, Blackness, Port Edgar) and six sites in the upper estuary between Kincardine and Stirling (Elliott *et al*., 1988).

In the Clyde the work of the CRPB culminated in the return of Atlantic salmon (*Salmo salar*) runs in the River Clyde in 1983 after an absence of over 100 years and there is now an established fishery with annual runs of both salmon and sea trout (*Salmo trutta*) up into the Clyde and also now into the Kelvin (Mackay & Doughty, 1986; Gardiner & Armstrong, 1996; FRS, 2003). Similarly, for the FRPB the return of the smelt (or sparling: *Osmerus eperlanus*) to the Forth Estuary in 1989, after an absence of 25 years, was a newsworthy occurrence (Edwards, 1989). The smelt is a species of conservation interest in Scotland with populations elsewhere restricted to the Tay and the Cree estuaries. However, there is now a thriving population re-established in the Forth Estuary (Maitland & Lyle, 1990, 1996).

Fish sampling in these estuaries has continued for over 30 years, carried on from 1996 by the Scottish Environment Protection Agency (SEPA). The primary purpose of these surveys was to provide evidence to feed into the water quality classification schemes developed by the Association of River Inspectors for Scotland (ADRIS, 1994) for the River Purification Boards and subsequently adopted by SEPA. The ADRIS Estuary Classification Scheme included an assessment of whether the passage of migratory species was free, or partly restricted, or wholly prevented (e.g. due to dissolved oxygen deficiencies). Similarly, the resident estuarine fish fauna was assessed as to whether it was consistent with the physical and hydrographical conditions or showed a reduction in species richness and occasional or frequent restrictions in usage of the estuary due to water quality factors. The principal factor limiting migratory or resident fish was dissolved oxygen sags caused by biological oxygen demand from sewage treatment works discharges.

The fish data collected included the species present and their abundances and in most surveys the length and weight of each fish specimen was also recorded, allowing more detailed investigations of the fish population dynamics. The status of the fish community in the Clyde Estuary was described by Henderson & Hamilton (1986). The fish data gathered from the Forth Estuary have spawned numerous publications (Poxton, 1987; Elliott *et al.*, 1988, 1990; Elliott & Taylor, 1989; Pomfret *et al.*, 1991; Greenwood *et al.*, 2002; Greenwood & Hill, 2003). Additional studies on fish entrapped on mesh screens at the Kincardine and Longannet power stations in the Forth Estuary have also provided further information on its fish community (Greenwood, 2008a,b; Greenwood & Maitland, 2009). The EU Water Framework Directive (2000) provided new impetus to assess the fish communities in Scotland's transitional waters and to develop new monitoring approaches which would be comparable throughout the U.K. and Europe.

THE EU WATER FRAMEWORK DIRECTIVE (WFD)

The EU Water Framework Directive (European Union, 2000) involves an integrated approach to assessing ecological quality in fresh waters, transitional waters, and coastal waters. Guidance on implementing WFD in these waters is provided via common implementation strategy documents (WFD-CIS, 2003a,b). The ecological communities assessed for transitional and coastal waters include benthic invertebrates, macroalgae/seagrasses, and phytoplankton; under WFD the fish communities are assessed in fresh waters and transitional waters but not in coastal waters where fisheries are regulated under the Marine Strategy Framework Directive and the EU Common Fisheries Policy (Greenstreet *et al.*, 2012).

The different ecological communities (called Biological Quality Elements under WFD) are assessed using different analytical tools to produce an ecological status or WFD class. There are five classes (High, Good, Moderate, Poor and Bad) which reflect an increasing gradient of environmental pressure and exhibit increasing deviation from completely natural reference conditions.

The assessment tools must each produce a score, called an Ecological Quality Ratio (EQR), which ranges between 0 and 1 and this range is divided into the five quality classes with 0 being at the lower end of Bad and 1 at the upper end of High. Moreover, a Good status in one country, for any biological quality element, must mean the same as in any other country. This is checked by a formal intercalibration process where countries compare results from different assessment tools for the same biological quality element using a common dataset for that element. Where results differ the class boundaries of specific assessment tools are adjusted so that the tools will provide similar classifications for relevant ecological data (Lepage *et al.*, 2013, 2016).

IMPLEMENTING THE DIRECTIVE

To implement WFD in the U.K. a Technical Advisory Group (UKTAG) was established and a task team formed for each biological quality element. The UKTAG Transitional Water Fish Task Team developed and tested assessment tools and provided guidance on monitoring strategies and sampling methods in readiness for commencing WFD monitoring in 2007 (Coates *et al.*, 2004, 2007). The recommended monitoring strategy involved annual sampling in representative transitional waters of different ecotypes. A multi-method sampling approach was proposed using a range of different fishing gear. The sampling programmes aimed to sample throughout the transitional water, in shallow and deep water, in inner and out parts of the water body, to gauge all components of the fish community. Depending on the size of the water body between 30 and 50 samples were deemed appropriate to characterise the fish community. Fish sampling was targeted in spring and autumn or, failing that, a more intense autumn sampling should suffice. The Transitional Fish Classification Index (TFCI) developed by Coates *et al.* (2007) was adopted as the assessment tool for fish communities in the U.K. (and Ireland). The application of this tool in the U.K. has been described in some detail in a UKTAG method statement and practitioner's guide (WFD-UKTAG, 2012, 2014a).

Although Scotland has over 500 marine water bodies designated under WFD, only 49 of these are categorised as transitional waters. Six different types of transitional waters are recognised within the UK (WFD-UKTAG, 2003) but only four of these types are found in Scotland. Of Scotland's estuaries, 27 are partly mixed/stratified, meso-/polyhaline, and mesotidal (Type TW2), and ten, situated in the Solway region, are mixed/stratified, meso-/polyhaline, and macrotidal (Type TW3). Scotland has 110 sea lochs (Edwards & Sharples, 1986) but only four of these have sufficient freshwater input to categorise them as Transitional Sea Lochs (Type TW5). Scotland has 103 saline lagoons (Angus, 2016) but only those 8 lagoons that are actually connected to an

adjacent transitional water are categorised as Transitional Lagoons (Type TW6).

While member states are required to provide classifications for all water bodies, they do not need to monitor all of them. Surveillance monitoring of a selection of water bodies that are representative of the different types is sufficient, along with monitoring of any other water bodies under significant anthropogenic pressure and at risk of being at less than Good ecological status. Results of the surveillance monitoring of one water body can be attributed, as proxies, to a group of similar water bodies with similar pressures. SEPA had previously monitored fish populations in the Clyde and Forth Estuaries, and had also conducted a little sampling in the Tay Estuary. In preparation for WFD monitoring, some additional fish surveys were undertaken in the Dornoch, Cromarty, and Beauly/Moray Firths (SEPA, 2005) as well as in Loch Eil, Gare Loch, and the Garnock Estuary. From all of these, six transitional waters were eventually selected as representative for Scotland's Transitional Water Fish assessments, with two from the east coast (North Sea Ecoregion) and four from the west coast (Atlantic Ecoregion) (Fig. 1). These six selected transitional waters actually comprise ten water bodies and have 13 associated water bodies which receive grouped classification from their parent water body (Table 1). For the other 26 transitional water bodies, remote from anthropogenic pressures and not included within any groups, the classification defaults to High for TW fish.

Fig. 1. Location of representative transitional waters for assessing transitional water fish communities. Marine water bodies shown in blue.

It should be noted that some of the transitional waters actually comprise more than one defined water body for WFD assessments (e.g. the Forth Estuary is composed of three water bodies – Upper, Middle, and Lower Forth Estuary) but, in contrast to other biological quality elements, the relatively mobile fish community is always monitored, assessed, and classified as a single entity across the whole estuary.

The Clyde and Forth are large estuaries with significant anthropogenic pressures. The Cromarty Firth and Garnock/Irvine are smaller estuaries with fewer pressures. Loch Eil and Gare Loch are transitional sea lochs with differing pressures. Although there are several macrotidal (TW3) water bodies along the Dumfries and Galloway coast, the fish communities here have not been assessed by SEPA, as the macrotidal régime makes field sampling very difficult and potentially dangerous. However, the Solway Estuary water body itself (which is a cross-border water body) is surveyed for fish on the English side and a classification for its transitional water fish is provided by the Environment Agency. The WFD UKTAG Transitional Waters Fish Task Team has taken the view that transitional water lagoons (TW6) are not appropriate for fish assessment as these water bodies are typically isolated from the sea, and their utilisation by marine fish species is probably very limited.

The Scottish TW Fish Monitoring Programme

Although some preliminary WFD surveys began in 2005, the monitoring programme for TW fish did not start properly until 2007 with the gradual introduction of the multi-method sampling approach in the representative transitional waters (Table 2). The methods utilised large and small beam trawls, pelagic trawls, beach seines, and fyke nets.

The large beam trawls were towed in deeper water along pre-set routes, usually between 0.6 and 1 km in length, using the SEPA survey vessel, *Sir John Murray*, or occasionally on the east coast, the *Alba na Mara* survey vessel from Marine Scotland. The SEPA beam trawl has a 2 m width metal frame with shoes on the lower side with 70 mm main mesh net and 40 mm cod-end mesh. The Marine Scotland beam trawl has a similar 2.7 m frame with 90 mm main mesh net and 50 mm cod-end mesh. The beam trawl catches were landed on deck and all the contained fish transferred to tubs for processing (Fig. 2A). In the Forth and Tay estuaries an Agassiz type beam trawl was used at deeper sites up until 2008 but replaced thereafter with a standard 2 m metal beam trawl. Pelagic mid-water trawls were trialled in the outer reaches of the Forth and Tay estuaries, and the Cromarty Firth, up until 2009, and also in the Clyde in 2010. However, the UKTAG Team then recommended against using pelagic trawls as they could be operated in only very limited areas, and potential catches of large shoals of pelagic fish, such as sprats (*Sprattus sprattus*), may skew the overall abundance data for the estuary. Hence, this sampling method was not used after 2010.

In shallower waters, a lighter 2 m width wooden beam (with metal shoes) was used or a shoeless mini-beam trawl, 1.5 m metal bar width and 10 mm mesh. The beam

Type	Location	Surface Area (Km^2)	Grouped water bodies.
TW2	Cromarty Firth	90.9	Dornoch Firth, Moray Firth, Beauly Firth, Lossie Estuary, Eden Estuary, Montrose Basin
TW2	Forth Estuary	86.5	Tay Estuary
TW5	Loch Eil	11.2	Loch Linnhe (North), Loch Etive.
TW5	Gare Loch	12.8	None
TW2	Clyde Estuary	75.2	None
TW2	Garnock/Irvine Estuary	1.6	Ayr Estuary, Girvan Estuary, Stinchar Estuary

Table 1. Representative transitional waters for fish assessment in Scotland.

Year	Beauly / Moray	Dornoch Firth	Cromarty Firth	Tay Estuary	Forth Estuary	Clyde Estuary	Garnock Estuary	Loch Eil	Gare Loch
2005	9B, 2F, 3S	4B, 1F, 1S	14B, 2F, 3S	12B, 1F, 1S, 4P	42B	12B	-	4B	-
2006	-	-	-	-	28B, 4P	8B	-	-	-
2007	-	-	13B, 4F, 5S, 2P	2B, 1P	24B, 6P	14B	2F	4B	10B
2008	-	-	10B, 4F, 4S, 1P	8B, 2F, 1S, 1P	26B, 1F, 1S, 3P	9B	2F	6B	9B
2009	-	-	2F, 1S, 2P	2B, 2F, 2S, 1P	36B, 2P	11B	2F	6B	7B
2010	-	-	-	-	-	12B, 4F, 4S, 8P	4F, 6S	-	8B, 3F, 5S
2011	-	-	-	-	15B, 4F, 10S	8F, 12S	-	-	-
2012	-	-	24mB, 8F, 16S	-	-	8F, 8S	-	10B, 8F, 19S	-
2013	-	-	-	-	-	10B, 8F, 18S	7mB, 10F, 16S	-	10B, 8F, 16S
2014	-	-	-	-	9B, 14mB, 8F, 16S	-	-	-	-
2015	-	-	21mB, 9F, 12S	-	-	-	-	6B, 4mB, 10F, 18S	-
2016	-	-	-	-	-	10B, 15F, 20S	-	-	-
2017	-	-	-	-	12mB, 3F, 8S	-	-	-	-
2018	-	-	-	-	4B	-	-	-	-

Table 2. Sampling programme and methods for transitional water fish, 2005-2018. B = beam trawl; F = fyke net; S = seine net; P = pelagic trawl; mB = mini-beam trawl.

trawls in shallower water were towed, for five or ten minutes, from various smaller craft, including RIBs (Fig. 2B). On shallow shelving shores beach seine nets were used with a two or three metre curtain wall and about 30 m long, with 6.5/14 mm mesh. The beach seines were dragged out in a large loop by wading out chest deep, or pulled out by a small rigid inflatable boat (RIB), and then hauled shoreward to encircle whatever fish were in the vicinity (Fig. 2C). In addition, double-ended fyke nets were deployed in shallow waters. These nets were 7-hoop large Double Dee, 1 m height, 10/14 mm mesh, with 10.6 m leader (no wings) or 5-Hoop Double-O, 10/14/17 mm mesh with 5.5 m leader and side wings, and all fitted with otter-guards. The fyke nets were staked in place with metal road pins at low water with just enough water to cover the trap ends and left for 12 hours to trap fish over one tidal cycle (Fig. 2D). Alternatively, the fyke nets could be lowered into shallow water from a RIB, with a small marker buoy and anchors/chains at either end to keep them in place for the duration of one or two tidal cycles. For all samplings all captured fish were transferred to holding tubs and then identified and measured and returned alive to the water. The topography and bathymetry of the transitional water dictated what type of fishing gear was appropriate and where it could be used, with the underlying aim of sampling all components of the fish community throughout the transitional water. As there were slight variations in gear, mesh sizes, trawl lengths or times, then the methods are not fully standardised and the resultant data are only semi-quantitative. Nevertheless these data are fit for the purposes of WFD qualitative assessments. The array of sampling sites and methods for the different transitional waters are shown in Fig. 3. Fish identification followed the standard guide for British and Irish waters (Maitland & Herdson, 2009).

The recommended sampling windows were spring (May/June) or autumn (September/October). It quickly became apparent that sampling of all six transitional waters every year was logistically unrealistic and SEPA adopted a programme of sampling each transitional water every third year. This would allow two classifications to be undertaken within each six-year WFD reporting cycle. In the first few years both spring and autumn sampling was carried out, but in later years it proved more efficient to focus all the sampling in autumn. Even then logistical issues arose and some transitional waters, such as the Clyde Estuary, were surveyed over two years, with the inner estuary one year and the outer estuary the following year. In such cases the data were amalgamated as if they came from a single year.

Fig. 2. Sampling gear. (A) Beam trawl. (B) Mini-beam trawl. (C) Beach seine. (D) Fyke net. (Photos: SEPA (A,C,D); DAERA NI (B))

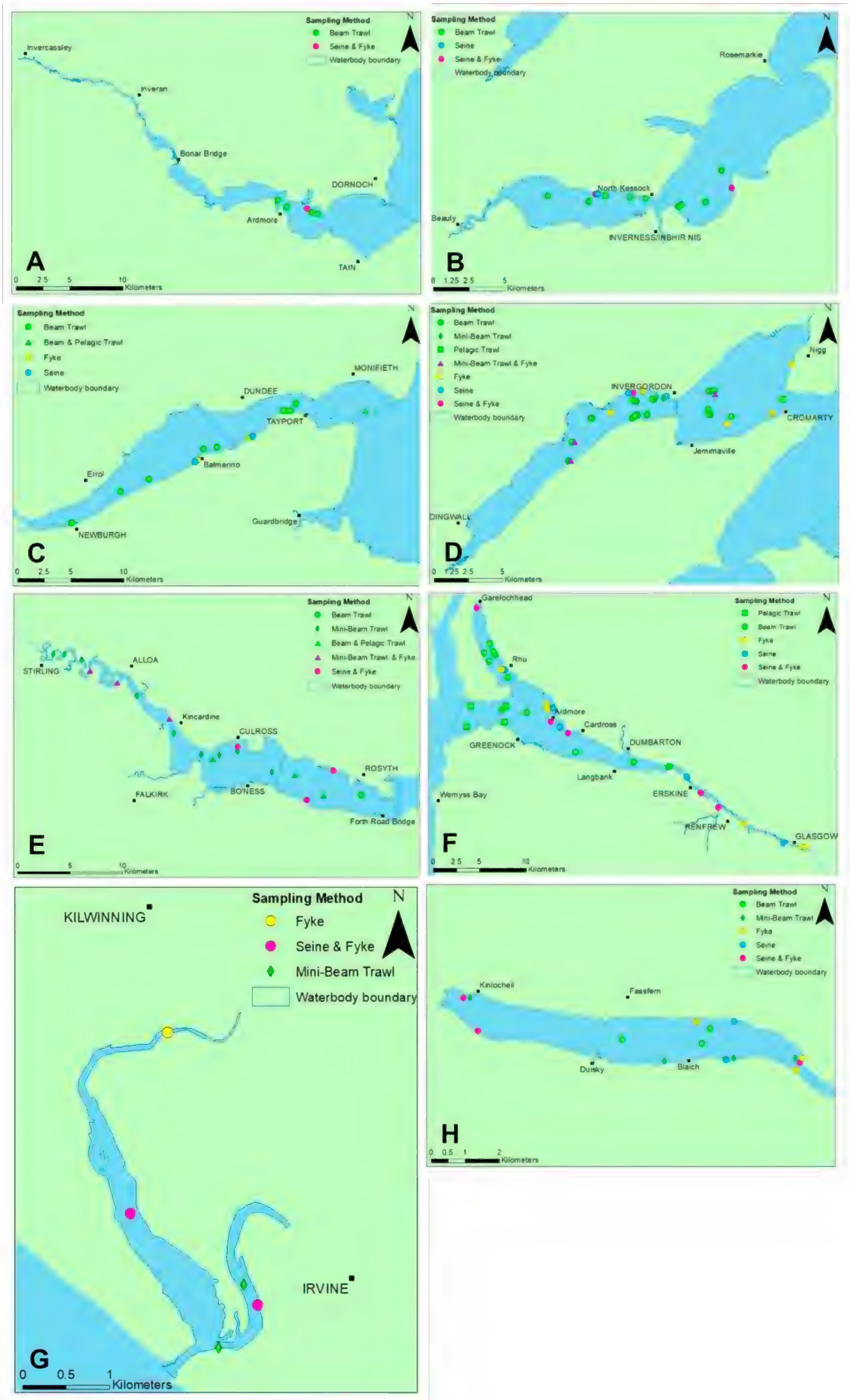

Fig. 3. Sampling sites and methods. (A) Dornoch Firth, 2005. (B) Beauly/Moray Firth, 2005. (C) Tay Estuary, 2005-09. (D) Cromarty Firth, 2005-15. (E) Forth Estuary, 2005-18. (F) Clyde Estuary and Gare Loch, 2005-16. (G) Garnock/Irvine Estuary, 2007-13. (H) Loch Eil, 2005-15.

The Transitional Water Fish Classification Index (TFCI)

The directive requires member states to examine the composition and abundance of the ecological communities and any sensitive species therein and gauge how far these have deviated from natural reference conditions. The TFCI assessment tool developed by the UKTAG Transitional Water Fish Task Team comprises ten community metrics of ecological relevance which evaluate the species diversity or composition, the species abundance, the nursery function and also the trophic integrity (WFD-UKTAG, 2014a).

The assessment tool requires that each fish species is categorised into specific ecological guilds following the approach developed by Elliott & Dewailly (1995), Elliott & Hemingway (2002), Elliott *et al*. (2007), and Franco *et al*. (2008). The TFCI tool utilises functional guilds and feeding guilds (WFD-UKTAG, 2012, 2014a). Functional guilds describe the lifestyle of a fish species - how it uses the estuary or transitional water. Estuarine Residents (ER) live their full lives in the estuary, and include species such as flounder (*Platichthys flesus*), eelpout (*Zoarces viviparus*), pogge (*Agonus cataphractus*), and sand goby (*Pomatoschistus minutus*). Marine Seasonals (MS) are marine fish which enter estuarine waters on a seasonal basis only and include species such as sprat, thicklip grey mullet (*Chelon labrosus*), grey gurnard (*Eutrigla gurnardus*), and five-bearded rockling *(Ciliata mustela*). Marine Juveniles (MJ) only spend the younger stages of their lives in estuaries, using the estuary as a nursery, and move back into fully marine waters as they mature. These include many important commercial fish species such as common dab (*Limanda limanda*), plaice (*Pleuronectes platessa*), common sole (*Solea solea*), herring (*Clupea harengus*), cod (*Gadus morhua*), whiting (*Merlangius merlangus*), and pollack (*Pollachius pollachius*), as well as smaller species such as sand smelt (*Atherina presbyter*). Catadromous and anadromous (CA) fish migrate from marine waters to freshwater to breed such as salmon, sea trout, smelt, river and sea lampreys (*Lampetra fluviatilis* and *Petromyzon marinus*), or *vice versa* for the European eel (*Anguilla anguilla*). They all pass through estuarine waters, where they may spend some time, and many of these species are particularly sensitive to reduced water quality or physical barriers and for this reason are regarded as indicator species. Some indicator species, such as the allis shad (*Alosa alosa*) and twaite shad (*A. fallax*) are now very scarce in Scottish waters, and others such as the sturgeon (*Acipenser sturio*) have long been extinct, apart from an occasional vagrant from elsewhere in Europe. Marine Adventitious (MA) species are marine species that are occasional visitors and wander into the estuary by accident. They include a wide variety of marine species and sometimes very unusual vagrants may turn up, such as a swordfish (*Xiphias gladius*) observed in the Forth Estuary in 2009 (BBC, 2009) and more recently in the Firth of Forth (McInerny & Hoey, 2021). Freshwater fish (FW) also form a functional guild that occasionally appears in the upper parts of estuaries, especially during high river flows.

The feeding guilds describe the predominant feeding mode or diet of a species. Most demersal fish are benthic invertivores (BI) – feeding on invertebrates on the seabed. These include flatfish (Pleuronectiformes), gurnards (Triglidae), gobies (Gobiiformes), and sea scorpions (Cottidae). Zooplanktivores (Z) pluck their prey from the water column and include herring, sprat, sandeels (*Ammodytes* spp.), smelt, sand smelt, as well as pipefish (Syngnathidae), and sticklebacks (Gasterosteidae). Piscivores (P) prey on other fish species and include salmon, cod, whiting, saithe (*Pollachius virens*), bullrout (*Myoxocephalus scorpius*), European eel, seabass (*Dicentrarchus labrax*), and also the parasitic sea and river lampreys. Finally, the grey mullets are categorised as detritivores (D) feeding on various types of organic detritus. It should be noted the feeding guilds allocated refer to the dominant feeding modes of adults. Salmon may be invertivores for parts of their life cycle and larval lampreys are filter-feeding detritivores.

Reference conditions and metric calculations

Once all the fish species and abundance data have been collected and the species allocated to their respective functional and feeding guilds, the ten metrics can then be calculated. However, the directive requires assessments of each biological quality element with respect to natural reference conditions for that ecological community. This means that a reference condition value for each metric in the TFCI is needed. Moreover, a separate set of reference conditions is required for each transitional water type and/or ecoregion. Hence, for Scottish waters these baseline reference conditions needed to be created by SEPA for North Sea TW2, Atlantic TW2, and Atlantic TW5 transitional waters.

Constructing reference conditions for all the metrics used an amalgamation of historical species richness records and more recent survey data on species occurrences and abundances. Such reference conditions based on scant historical records and limited datasets are far from ideal but do at least provide a standardised baseline using the best information available. The finalised Reference Condition spreadsheets are held by SEPA and copies are used as workbook templates for carrying out subsequent classifications. The Scottish reference condition values for transitional waters fish are presented in the TFCI Method and the Practitioner's Guide (WFD-UKTAG, 2012, 2014a) along with notes on calculating the metrics and carrying out an assessment and classification.

The approach to developing Scottish reference conditions is described here for the first time and involved some hindcasting by looking at historical records of fish in Scottish transitional waters and also looking at more recent fish datasets to determine the most suitable data which can be used to set a boundary for reference conditions. As the Scottish survey data are

limited to only a few transitional waters they were augmented with transitional water fish data from nearby regions with similar water body types. For TW2 (North Sea), SEPA survey data from the Cromarty, Forth, and Tay from 2005-12 was used with additional data provided from the Environment Agency surveys in north-east England from the Coquet, Esk, Tees, Tweed, Tyne and Wear Estuaries over 2010-12. For TW2 (Atlantic), SEPA data from the Clyde and Garnock from 2005-11 was used with additional data provided from Northern Ireland Environment Agency surveys in the Bann, Connswater, Foy and Fau, Laggan, Newry, and Roe Estuaries over the period 2010-11. For TW5 (Atlantic) SEPA data from Gare Loch and Loch Eil from 2005-12 was used with additional survey data provided from the Scottish Marine Biological Association (SMBA) surveys in Loch Eil and Loch Etive over the period 1968-76.

For species richness, the historical records for a transitional water are treated as if they were a single annual survey and ranked with the recent annual survey data from relevant surveys. The upper five ranked surveys with the highest species richness were taken as a quintile cut-off for the reference condition value range. The historical literature consulted to help construct reference conditions is shown in Supplementary File 1. For estimating historical species richness for the North Sea TW2 all historical species records from the Cromarty Firth and the Tay and Forth Estuaries were collated. Added to these were any fish species records of the ER, MJ, MS, CA, and FW functional guilds recorded from adjacent coastal waters bodies or upstream riverine water bodies. However, the availability of historical data was skewed towards the Forth such that it had 67 species, with only 20 species from the Cromarty and eight from the Tay. The historical species richness records form the Cromarty Firth and Forth and Tay Estuaries were ranked against more recent data from 2005-12, and data from the NE England estuaries from 2010-12. Similarly for the Atlantic TW2, any historical records from the Clyde Estuary were collated and added to these were any fish species of the ER, MJ, MS, CA, and FW functional guilds recorded from the adjacent Clyde Sea Area coastal waters bodies or upstream riverine water bodies. The historical species richness for the Clyde Estuary and adjacent Clyde Sea Area was 58 species which was ranked against the recent datasets from the Clyde, the Garnock and Northern Ireland, with the upper quintile cut-off used as before to define the reference value range. However, for Atlantic TW5 no appropriate historical data was available, so just the SEPA 2005-12 and SMBA 1968-76 survey data from Gare Loch, Loch Eil, and Loch Etive were used for ranking without adding any records from adjacent coastal waters, and the upper quintile cut-off used as before to define the reference conditions range.

For the metrics in the TFCI tool the uppermost reference value is either the maximum value found using the reference survey data or, for Metric 2, Metric 7, and Metric10, the maximum possible value. This maximum value is divided into five equal bands with the upper band being the reference condition value range. Each of the five bands of metric values is assigned an individual metric score which can only be a whole number between 1 and 5, with the lower band scoring 1 and the upper band, the reference condition range, being score 5. It is the metric scores (not the metric values) that are added to produce the final Ecological Quality Ratio (EQR).

For Metric 1 (species composition) reference value the species from all the surveys are ranked according to their frequency of occurrence over the survey/sampling years, with most frequent ranked first, and the species richness value cut-off number (as derived above) now used to determine the number of upper ranked species that appear as the Metric 1 reference list species. Metric 1 calculation involves a Bray-Curtis similarity analysis between the species captured and the reference list species. The Bray-Curtis percentage similarity is divided into five equal bands of 20% to give five possible metric scores. For TW2 (North Sea), TW2 (Atlantic), and TW5 the number of reference species is 22, 26, and 29 respectively (WFD-UKTAG, 2012, 2014a) with the relevant reference species highlighted in bold in the Supplementary Files.

For Metric 2 (number of indicator species) the reference value is where all nine indicator species (see above under CA guild) are present and for Metric 2 calculation the number of indicator species captured is compared with this. The reference value of 9 is divided into five equal bands to give five possible metric scores.

For Metric 3 (species relative abundance) reference value, the percentage proportionate abundance of each species per sampling year is calculated, and then the average relative abundance over the survey/sampling years is ranked, with highest relative abundance ranked first. Again, the upper quintile value for species richness (as described above) is used to determine the number of top-ranked species that appear as the Metric 3 reference species. The actual reference species selected is likely to differ (albeit slightly) from those in Metric 1. Metric 3 calculation involves a Bray-Curtis similarity analysis between the relative abundances of the species captured and the relative abundances of the reference list species as shown for each type in the Practitioner's Guide (WFD-UKTAG, 2012, 2014a) and also shown in the Supplementary Files. The Bray-Curtis percentage similarity is divided into five equal bands of 20% to give five possible metric scores.

For Metric 4 (number of species within 90% abundance) reference value, the percentage proportionate abundances of each species per survey/sampling year is used to determine the number of species comprising 90% abundance by selecting the most abundant species first. The number of species per sampling year is then ranked (with highest number of species ranked first) and the average of the upper quintile of the ranking used as the reference value. For Metric 4 the reference value is divided into five equal bands to give five possible metric scores.

Metrics 5 to 10 simply involve counting the number of species present within a specific functional or feeding guild (i.e. number of species in ER, MS/MJ, BI, and P for Metrics 5, 6, 8 and 9), or the number of functional or feeding guilds present for Metric 7 and Metric 10. Reference values for metrics 5, 6, 8 and 9, involve counting the no. of species in the respective guild per survey/sampling year and ranking these, with highest first, and taking the average of the top quintile as the reference value. Metric 6 (Estuary Dependent Species) is a simple combination of the number of Marine Seasonal (MS) and Marine Juvenile (MJ) species. For Metric 7 and Metric 10 the reference value is the presence of all six functional guilds or all four feeding guilds. For Metrics 5 to 10 the reference value is divided into five equal bands to give five possible metric scores. The reference condition range of values (i.e. the upper fifth band) for Metrics 1 to 10 for TW2 (North Sea), TW2 (Atlantic), and TW5 are shown in Tables 3 - 5.

The TFCI is the sum of all ten metric scores. As these scores are whole numbers between 1 and 5 then the TFCI range has a minimum value of 10 and maximum of 50. To convert this range to an Ecological Quality Ratio (EQR), simply take the (score sum – 10) and divide by 40 which produces an EQR range between 0 and 1, as required by the directive. The class boundaries for the EQR are initially set by dividing the EQR into five equal class bands (i.e. 0 - < 0.2, 0.2 - < 0.4, 0.4 - < 0.6, 0.6 – 1.0) but these are then adjusted following intercalibration with other EU member states where a common data set for each particular biological quality element was analysed by the different tools used in each member state (European Commission, 2013; Lepage *et al.*, 2013, 2016). Only the boundaries between High/Good and Good/Moderate were reset during intercalibration (High is 0.81 – 1.0, Good is 0.58 - < 0.81) as these are the most crucial boundaries with respect to a member state having, or not having, to introduce improvement measures.

RESULTS

Survey findings

Between 2005 and 2018, SEPA carried out 44 assessments of fish communities in nine different transitional waters. A total of 912 samples were collected, using five different sampling methods, which captured 39,563 fish of 67 different species. The species captured and the abundances per sampling year are shown in Supplementary Files 2–4.

Preliminary surveys in the Dornoch Firth (Fig. 3A), the Beauly/Moray Firths (Fig. 3B), and the Tay Estuary (Fig. 3C) are included here, although none of these was adopted as representative transitional waters. It should be noted that the initial surveys in selected transitional waters have not always employed a multi-method sampling approach nor has the sampling effort been spread across the transitional water or attained the 30 samples deemed sufficient for confident WFD assessment. Hence, only a limited number of later surveys are fully valid for undertaking WFD assessments. No fish surveys have been undertaken since 2018.

For TW2 estuaries on the east coast (North Sea Ecoregion) the surveys, with 488 samples, have landed 14,906 fish with 45 species recorded (Supplementary File 2). The most abundant fish were sprat (5,693), flounder (2,567), plaice (1,495), cod (1,403), whiting (622), smelt (542), and herring (518), with smaller numbers of sand goby (493), pogge (317), bullrout (261), and common goby (*Pomatoschistus microps*) (164). Some species such as haddock (*Melanogrammus aeglefinus*), ling (*Molva molva*), lesser sand-eel (*Ammodytes marinus*), two-spotted goby (*Gobiusculus flavescens*) and mackerel (*Scomber scombrus*) are represented by single specimens only. The sampling effort in the Dornoch Firth, Beauly/Moray Firths, and the Tay Estuary is insufficient to characterise the fish communities in these water bodies, though it is noteworthy that the Tay Estuary sampling does highlight the presence of smelt, as well as a few sea trout, salmon, and river lampreys.

The Cromarty Firth (Fig. 3D) harboured 35 species with a total catch of 3,126 fish for 167 samples. This was dominated by sprat, representing 60% of the total Cromarty catch, but these mostly derive from 1,851 fish captured in shoals in 2009 and 2012. Other common Cromarty fish included bullrout (108), cod (79), pogge (63), saithe (56), flounder (53), three-spined stickleback (*Gasterosteus aculeatus*) (52) and whiting (50). There were only a few migratory fish captured; sea trout (19), salmon (7), and European eel (2).

The Forth Estuary (Fig. 3E) harboured 35 species with a total catch of 10,478 fish for 274 samples. The Forth Estuary is similar in size to the Cromarty Firth and the same number of species was recorded. However, the overall sampling effort is much greater in the Forth which explains the higher total fish catch. Again, the catch is dominated by sprat (3,734), which account for 36% of the total abundance, but 71% of the sprat derive from shoals captured by beach seining at Limekilns in 2011. The next most dominant fish was flounder (2,391), which represents 23% of the total Forth catch. Other common Forth fish include plaice (937), cod (778), whiting (531), smelt (481), herring (465), sand goby (445), and pogge (228). It is evident that the Forth Estuary still functions as an important nursery area for commercial fish species as described by Elliott *et al.* (1990). In addition to the smelt, other migratory species occurred in small numbers: European eel (20), sea trout (13), river lamprey (7), and salmon (2).

For TW2 estuaries on the west coast (Atlantic Ecoregion) the surveys, with 240 samples, have landed 18,687 fish with 42 species (Supplementary File 3). The Clyde Estuary is nearly fifty times larger than the Garnock Estuary and has had nearly four times the sampling effort, so unsurprisingly 92% of the total catch was recovered from the Clyde.

Metric	Ref. Values Range	Cromarty 2012 Values	Cromarty 2015 Values	Forth 2014 Values	Forth 2017/18 Values	Cromarty 2012 Scores	Cromarty 2015 Scores	Forth 2014 Scores	Forth 2017/18 Scores
1. Species composition	80 -100	69.8	62.2	66.7	73.2	4	4	4	4
2. No. of Indicator spp.	7.2 - 9	3	1	3	1	2	1	2	1
3. Relative Abundance	80 - 100	40.9	30.3	53.3	50.6	3	2	3	3
4. No. of species for 90% Abundance	6.8 - 8.5	4.8	8.1	7.3	4.9	3	5	5	3
5. No. of Estuarine Resident (ER) spp.	6.8 - 8.6	8	10	8	7	5	5	5	5
6. No. of Estuary Dependent (MS + MJ) spp.	5.8 - 7.3	4	6	7	7	3	5	5	5
7. No. of Functional Guilds	4.8 - 6	5	5	5	5	5	5	5	5
8. No. of Benthic Invertivore (BI) spp.	7.3 - 9.1	11	15	15	10	5	5	5	5
9. No. of Piscivore (P) spp.	5.3 - 6	6	5	7	5	5	4	5	4
10. No. of Feeding Guilds	3.2 - 4	3	3	3	3	4	4	4	4
Sum of Metric Scores						39	40	43	39
Environmental Quality Ratio (EQR)						0.725	0.75	0.825	0.725
Classification						Good	Good	High	Good
No. of samples						48	42	47	27

Table 3. Metric values, scores and classification for TW2 (North Sea), Cromarty Firth and Forth Estuary, 2012–2018.

Metric	Ref. Values Range	Clyde 2010/11 Values	Clyde 2012/13 Values	Clyde 2016 Values	Garnock 2013 Values	Clyde 2010/11 Scores	Clyde 2012/13 Scores	Clyde 2016 Scores	Garnock 2013 Scores
1. Species composition	80 - 100	72.4	66.7	69.6	63.4	4	4	4	4
2. No. of Indicator spp.	7.2 - 9	3	3	2	2	2	2	2	2
3. Relative Abundance	80 - 100	47.9	32.3	50.8	41.0	3	2	3	3
4. No. of species for 90% Abundance	4.7 - 5.9	6.8	4.3	4.8	6.0	5	4	5	5
5. No. of Estuarine Resident (ER) spp.	7.7 - 9.6	12	7	8	7	5	4	5	4
6. No. of Estuary Dependent (MS + MJ) spp.	7.4 - 9.3	9	8	6	5	5	5	4	3
7. No. of Functional Guilds	4.8 - 6	6	6	5	4	5	5	5	4
8. No. of Benthic Invertivore (BI) spp.	11.4 - 14.2	17	13	10	6	5	5	4	3
9. No. of Piscivore (P) sp.	5.2 - 6.6	7	8	4	5	5	5	4	4
10. No. of Feeding Guilds	3.2 - 4	4	3	3	3	5	4	4	4
Sum of Metric Scores						44	40	40	36
Environmental Quality Ratio (EQR)						0.85	0.75	0.75	0.65
Classification						High	Good	Good	Good
No. of samples						48	52	45	34

Table 4. Metric values, scores and classification for TW2 (Atlantic), Clyde and Garnock/Irvine Estuaries, 2010–2016.

Metric	Ref. Values Range	Loch Eil 2012 Values	Loch Eil 2015 Values	Gare Loch 2010 Values	Gare Loch 2013 Values	Loch Eil 2012 Scores	Loch Eil 2015 Scores	Gare Loch 2010 Scores	Gare Loch 2013 Scores
1. Species composition	80 - 100	64.2	63.2	64.0	54.5	4	4	4	3
2. No. of Indicator species	7.2 - 9	3	2	1	1	2	2	1	1
3. Relative Abundance	80 - 100	33.2	40.8	40.4	45.7	2	3	3	3
4. No. of species for 90% Abundance	8.3 - 10.3	9.8	11.7	4.2	5.7	5	5	3	3
5. No. of Estuarine Resident (ER) species	6.6 - 8.2	7	9	7	8	5	5	5	5
6. No. of Estuary Dependent (MS + MJ) species	7.8 - 9.8	5	7	7	8	3	4	4	5
7. No. of Functional Guilds	4.8 - 6	5	5	5	5	5	5	5	5
8. No. of Benthic Invertivore (BI) species	16.4 - 20.5	14	20	15	18	4	5	4	5
9. No. of Piscivore (P) species	6 - 7.5	8	6	4	5	5	4	3	4
10. No. of Feeding Guilds	3.2 - 4	3	3	3	4	4	4	4	5
Sum of Metric Scores						39	41	36	39
Environmental Quality Ratio (EQR)						0.725	0.725	0.65	0.725
Classification						Good	Good	Good	Good
No. of samples						37	38	16	34

Table 5. Metric values, scores and classification for TW5 (Atlantic), Loch Eil and Gare Loch, 2010 – 2015.

In the Clyde Estuary (Fig. 3F), 189 samples landed 17,167 fish, with 41 species, and the most dominant fish were flounder (4,470) and sprat (4,420) accounting for 26% and 25.7% respectively of the total abundance. The next most abundant fish in the Clyde Estuary were sand goby (1,918), common dab (1,696), sand smelt (1,576), and plaice (1,427) with other common fish being pogge (326), eelpout (229), long-spined sea scorpion (*Taurulus bubalis*) (218), small sandeel (*Ammodytes tobianus*) (132), bullrout (129), cod (120) and common goby (118). Concealed within the data is the occasional serendipitous capture of fish shoals with nearly 80% of the total sprat catch derived from just two beach seine samples in 2013 and 67% of the total sand smelt from just two beach seine samples in 2016. Migratory species recorded included small numbers of European eel (30), salmon (17), and sea trout (9). Some species such as greater pipefish (*Syngnathus acus*), red gurnard (*Chelidonichthys cuculus*), goldsinny wrasse (*Ctenolabrus rupestris*), snake blenny (*Lumpenus lampretaeformis*), spotted dragonet (*Callionymus maculatus*), and roach (*Rutilus rutilus*) are represented in the Clyde Estuary by only single specimens.

In the Garnock Estuary (Fig. 3G), 51 samples landed 1,520 fish, with 25 species, of which the most abundant was the sand goby (872), which accounted for 57% of the total abundance. All but one of these sand gobies were captured in two (of the six) sampling years due to the introduction of the beach seining method. Other common species included flounder (180), plaice (113), and pollack (92). Migratory species recorded included small numbers of European eel (9), and sea trout (3). In 2010, a single perch (*Perca fluviatilis*) and single minnow (*Phoxinus phoxinus*) were captured, presumably due to high river flows at the time. It might seem likely that the small size of the Garnock Estuary, compared with the Clyde Estuary, would explain its lower species diversity but the Clyde Estuary survey of 2012/13 with a similar number of samples (52), shows a similar number of species (25), and has a fairly similar abundance (1,878), if the shoal of 3,887 sprat is excluded.

For TW5 sea lochs on the west coast (Atlantic Ecoregion) the surveys, with 171 samples, have landed 5,970 fish with 49 species (Supplementary File 4). Although Loch Eil and Gare Loch are of similar size, and harbour the same number of species, the total catch in Gare Loch is over five times that of Loch Eil despite the latter having a greater sampling effort. The dominant fish also appear to be quite different in the two lochs.

For Loch Eil (Fig. 3H), 95 samples landed 1,125 fish for 38 species. The most abundant fish were two-spotted goby (221), common dab (209), poor cod (*Trisopterus minutus*) (120), and 15-spined stickleback (*Spinachia spinachia*) (115), with smaller numbers of whiting (76), common dragonet (*Callionymus lyra*) (53), cod (49), and long rough dab (*Hippoglossoides platessoides*) (47). Of these the two-spotted goby was only found in Loch Eil. Migratory species encountered included European eel (40), salmon (1), and sea trout (40). A wide variety of other species was captured in smaller numbers including eight found only in Loch Eil: great spotted dogfish (*Scyliorhinus stellaris*) (1), thornback ray (*Raja clavata*) (2), skate (*Dipturus batis*) (1), blue whiting (*Micromesistius poutassou*) (1), three-spined stickleback (13), red gurnard (3), corkwing wrasse (*Symphodus melops*) (4), and reticulated dragonet (*Callionymus reticulatus*) (5). In Loch Eil three different species of dragonet were recorded. Females of the spotted and the reticulated dragonets can be quite difficult to distinguish.

For Gare Loch (Fig. 3F), 76 samples landed 5,970 fish for 38 species. The most abundant fish were common dab (2,712), plaice (786), long rough dab (613), and sand goby (253). Other common fish included cod (73), common dragonet (67), common sole (61), and flounder (51). The only migratory species present were sea trout (7). Five species were recorded exclusively from Gare Loch; Nilsson's pipefish (*Syngnathus rostellatus*) (1), thicklip grey mullet (3), shanny (*Lipophrys pholis*) (1), snake blenny (16), Fries's goby (*Lesueurigobius friesii*) (2), and solenette (*Buglossidium luteum*) (9). The Fries's goby is associated with the burrows of Norway lobsters (*Nephrops norvegicus*), which occur in the deeper parts of the loch. Note that four of the TW5 Reference species spurdog (*Squalus acanthias*), herring, mackerel, Norway pout (*Trisopterus esmarkii*) - were not captured in any of the SEPA surveys in TW5 waters.

Classification assessments

The TFCI tool was applied to the full set of SEPA data from 2005 to 2018. The Ecological Quality Ratio (EQR) and the WFD class, are shown for all years in Supplementary Files 2, 3 and 4 but only those surveys in later years, where a sufficient number of samples has been collected across the whole estuary using the full suite of sampling methods, should be regarded as valid. For these latter surveys further details of the individual metric values, compared with the reference condition range of values, are shown in Tables 3, 4, and 5. The Forth 2017/18 sampling is also included here for comparison, even though the numbers of samples recovered fell just below the minimum required.

DISCUSSION

SEPA's approach to monitoring and classification of TW fish communities has evolved over the years. Previously, sampling of estuarine fish was more limited in scope with only two main transitional waters monitored, with fewer methods and less spatial coverage. The former ADRIS estuary classification scheme included only three classification levels (A/B, C, and D) for the migratory and resident fish and these were based on relatively simple qualitative factors (ADRIS, 1994). For Class A or B (Excellent or Good) the water quality allowed free passage of migratory fish and the resident fish community was normal. For Class C (Unsatisfactory) the water quality caused some restriction on the passage of migratory fish and the resident fish community was modified. For Class D (Seriously Polluted) passage of migratory fish was wholly prevented and the resident fish community

impoverished. Discrimination between classes A and B was determined by other water quality measures including dissolved oxygen and persistent pollutant levels.

Under ADRIS the focus was on water quality assessment, with some support from qualitative biological monitoring. However, under WFD, the emphasis has been on ecological community assessment, with some support from water quality monitoring. The WFD classification for TW Fish utilises new analysis tools and semi-quantitative methods. Preliminary WFD sampling for transitional fish commenced in 2005 with a view to running provisional classifications from 2007. Some of the transitional waters initially investigated (Dornoch and Beauly/Moray Firths, and Tay Estuary) were subsequently dropped from the list of tentative representative waters. Early attempts to utilise mid-water pelagic trawls as one of the sampling methods were later abandoned, as recommended by the UKTAG TW Fish Task Team, as these nets proved difficult to deploy in the confined spaces of estuaries and the catch data were of limited value. While a multi-method approach, using beam trawls, fyke nets and beach seines, was eventually settled upon, it was some considerable time before this was introduced to the sampling programme for each of the representative surveillance waters (see Table 2). The use of the mini-beam trawl which could be operated in shallower waters from a RIB did not take place until 2012. The use of fyke nets staked in the intertidal was found to have some drawbacks. To ensure the fyke trap-ends remained covered with water at all times, the nets had to be set in the shallows around the time of low water. The nets were then left for a 12-hour tidal cycle. To avoid unauthorised access, or theft, of the nets the setting time had to be close to nightfall so the nets would be quickly concealed, and the nets recovered early the next morning on the falling tide. From 2014, the deployment method changed with the nets still set around low water but dropped in the shallow sublittoral zone from small boats. These fykes were fixed by small anchors and marked by pellet buoys. As the nets were already fully submerged at the time of deployment, they were inaccessible from the shore and there was much more flexibility regarding the deployment times. However, this meant that they were always set in deeper water compared with previous settings just below the low tide level.

It had been initially envisaged that the six representative transitional waters in Scotland might be surveyed and assessed on an annual basis, but with many other demands on SEPA's boat crew and scientific staff, this proved too ambitious to fit into SEPA's busy work programme. A revised plan to sample each transitional water every third year was proposed, allowing two assessments within the standard WFD six-year reporting cycle. However, even this proved difficult at times and compromises had to be made. Initially both spring and autumn sampling was undertaken, as recommended in the UKTAG guidance, but it proved easier to timetable all the sampling into an intensive autumn schedule as permitted by UKTAG. However, this had inherent risks if some of the sampling was missed due to poor weather and could not be repeated before the autumn sampling window expired. In fact, for some estuaries, only part of the estuary was sampled one year with the remainder sampled the following year and the data combined and assessed as if collected in a single year (e.g. Clyde 2010/11, Clyde 2012/13, Forth 2017/18). Other planned surveys were cancelled due to lack of appropriate vessels within the required sampling windows. From 2016, SEPA's focus for marine monitoring switched almost entirely towards the aquaculture sector with WFD fish monitoring being de-prioritised and no TW fish sampling has been undertaken since 2018.

Although provisional classifications were attempted, the application of the TFCI remained invalid until the determination of reference conditions for each transitional water type was finalised. This required the collation of reference datasets, including comparative datasets derived from a multi-method sampling approach, from Scotland, north-east England and Northern Ireland. The reference conditions for western Scotland (Atlantic Ecoregion) were completed in 2012 and those for eastern Scotland (North Sea Ecoregion) completed in 2014. This finally enabled proper classifications to be undertaken and the TFCI could also be applied to the previous sampling data back to 2005, with the caveat that only those assessments with sufficient samples (i.e. >30), which utilise multi-method data collected from throughout the representative transitional water, should be regarded as fully valid. Hence, many of the EQR and classification results shown in Supplementary Files 2-4 do not fully meet these criteria and should be viewed with some caution. Only those EQR results shown in more detail in Tables 3-5 (excluding Forth 2017/18) are of acceptable confidence.

The introduction of multi-method sampling, corresponding with additional sampling sites, appears to have added new species to the monitoring tallies in some of the water bodies, pointing to the efficacy of this approach. For the Clyde Estuary the broadened sampling regime introduced in 2010 appears to add European eel (30), salmon (17), sea trout (9), sand-smelt (1,576), three-spined stickleback (55), and perhaps a few other species in smaller numbers, as well as elevated abundances of sprat and small sandeel. Sampling in upper reaches of the Clyde Estuary also added a few freshwater stragglers such as perch, roach, and minnow. Similarly, in the Garnock Estuary from 2010 a new sampling regime adds several new species and elevated abundances, mostly from the use of beach seines. However, the appearance of the common goby in 2010 in both estuaries is probably is due to this species being previously overlooked and an improved ability, following NMBAQC workshops, to distinguish this species from the sand goby.

For TW5 (Atlantic) sea lochs the introduction of the multi-method approach, with new sampling sites in Gare Loch in 2010 appears to have resulted in catches of ten

new species: sea trout (7), pollack (6), saithe (3), hake (1), sand smelt (16), 15-spined stickleback (7), Nilsson's pipefish (1), long-spined sea scorpion (5), thicklip grey mullet (3), and shanny (1). In Loch Eil, only beam trawl samples were used between 2005 and 2009 and the catch abundances were very low. Significantly elevated abundances and 22 new species were added after the extended sampling regime commenced in Loch Eil in 2012.

The fish communities of the three types, TW2 (North Sea), TW2 (Atlantic), and TW5 (Atlantic) show a variety of differences in their species compositions. The differences between TW2 (Atlantic) and TW5 (Atlantic) may be partly blurred by the physical connection between Gare Loch and the Clyde Estuary. Although the east and west coasts of Scotland are designated as different ecoregions under WFD there is no obvious and consistent difference of fish species between east and west. Only the east coast has catches of river lampreys or smelt, but these are also known to occur on the west coast, even if not captured in the SEPA WFD surveys. The sand smelt, which superficially resembles smelt (but is not closely related), was frequently captured on the west coast but is not recorded in the SEPA east coast surveys, although its presence in the Forth is indicated within the east coast reference conditions. The addition of new species cited above in relation to a broadened sampling regime may be due in part to simply collecting more samples. Ideally, to gain a representative sampling of a water body, sampling should be continued, by whatever methods, until no further new species are added. Hence a rarefaction curve of the cumulative number of species captured against the number of samples would gradually flatten out as the number of species peaks and few or no new species are added. Investigations by the UKTAG TW Fish Task Team indicated that such curves usually begin to flatten after around 30 samples, so survey plans usually set this as a minimum number of samples and have generally capped the planned number of samples at 50. While continued sampling thereafter may find the occasional rare species, the effect on the individual metrics and the overall assessment is likely to be negligible. Long term historical records suggest that continued recording will continue to add rarer Marine Adventitious (MA) species such as the extremely rare vagrant swordfish already mentioned.

For TW2 estuaries (North Sea) only the Cromarty Firth 2012, 2015, and Forth Estuary 2014 fully meet the aspirations of a multi-method approach with sufficient sample numbers and geographical spread of the sampling effort. The Forth Estuary survey in 2008 used four methods but (1) only collected a single fyke and single seine sample, (2) in 2009 only two methods were used, and (3) in 2011 no sampling took place in the upper estuary. In 2017/18 the Forth Estuary sampling fell just short of the minimum number of samples due to bad weather and gear damage, but details of this assessment are included here as a comparison for the 2014 survey. For TW2 estuaries (Atlantic) the sampling only fully met the requirements in the Clyde Estuary 2010/11, 2012/13, 2016 and the Garnock Estuary in 2013, and for TW5 (Atlantic) sea lochs only Loch Eil in 2012, 2015 and Gare Loch in 2013. These WFD classification results indicate that the fish communities in Scotland's representative transitional waters are currently in Good or High ecological status, at least for the fish biological quality element. The reduction in sampling effort in the Forth Estuary in 2017/18, to below the recommended minimum, appears to cause the class to drop from High to Good. This indicates that reduced sampling effort may result in false class downgrades. The importance of gaining enough samples to ensure confidence in the classification results cannot be over-emphasized.

A closer look at the individual metric values compared with the upper and lower boundaries for reference conditions provides more information on the fish communities. This is shown for the valid assessments highlighted above, along with a couple of examples, Gare Loch 2010, and Forth Estuary 2017/18, where the number of samples was insufficient (Tables 3-5). The upper reference boundary value is divided into five equal bands (quintiles) to give boundaries for the metric scores 1 to 5, with band 5 being equivalent to the reference condition boundaries. Few of the metric value boundaries end up being whole numbers yet most of the metric values measured can only be whole numbers, so in practice the lower metric value boundaries often have to be rounded up to the next whole number. For the number of indicator species, for example, the lower reference boundary is a metric value of 7.2 (i.e. the maximum value 9 minus a fifth of the maximum value, 1.8). Thus in practice six or seven indicator species will have a metric score of 4, and eight or nine indicator species will achieve a metric score of 5.

The reduction in the number of samples for the Forth Estuary in 2017/18 compared with 2014 affected the scores for Metrics 2, 4, and 9, and brought the classification down from High to Good (Table 3). For Gare Loch 2010, doubling the number of samples in Gare Loch 2013 increased scores for Metrics 6, 8, 9, and 10 with a decrease for Metric 1 score. Although the EQR increased, the classification remained within Good (Table 5).

The results suggest it would be beneficial to further investigate the possible effect of the number of samples collected on the actual EQR scores and perhaps up the threshold for the acceptable number of samples. However, in the data here it is difficult to disentangle the effects of number of samples from the effects of introducing new sampling methods as shown in Table 2. Comparing the reference condition value range with the recorded values for each metric casts some light on which metrics have most influence on the overall EQR.

For Metric 1, the species composition, similarity value ranges were similar for each water body type, mostly between 60 and 80%, with none attaining the reference condition range of 80-100%. For Metric 3, the relative abundance, similarity ranges were all much lower,

within the 30–60% range. The inherent complexity and variability of fish communities with respect to species composition and relative abundances perhaps makes it more difficult to achieve a close match to the defined reference conditions for these metrics.

For Metric 4, the number of species making up 90% of the abundance, the recorded metric value range between four and 11 species was broadly the same for each type and for TW2 (Atlantic) and TW5 (Atlantic) actually exceeded the upper reference condition boundary in some cases, suggesting that the upper boundary ought to be reviewed. For Metric 5, the number of Estuarine Resident (ER) species, the recorded metric value range was 7 to 12, mostly within the reference condition boundaries but also again exceeded the upper boundary in some cases. For Metric 6, the number of estuary dependent species (Marine Seasonals (MS) and Marine Juveniles (MJ)), the metric value range at 4 to 9, was relatively broad and frequently within the reference condition boundaries.

Metrics 7 and 10 (functional and feeding guild composition) showed little variation in metric values. There were no catches from the freshwater (FW) functional guild in TW2 (North Sea), TW5 (Atlantic), or in the Garnock/Irvine Estuary 2013 and Clyde Estuary 2016, both TW2 (Atlantic). This may have been due to insufficient sampling in the upper (reduced salinity) reaches of these water bodies. It should be noted that the three-spined stickleback which is often captured in these transitional waters is categorised as an anadromous species (CA guild) rather than a freshwater one. Of the four feeding guilds the maximum metric value of 4 was only occasionally reduced due to the absence of detritivores (D), which are represented here solely by thicklip grey mullet.

For Metric 8, the number of benthic invertivores (BI), the metric value range for TW2 (North Sea) was 10 to 15, all above the upper reference condition boundary, for TW2 (Atlantic) the range, 6 to 17, was broader and again exceeded the reference upper boundary, while for TW5 (Atlantic), the range, 15 to 20, was mostly within the reference condition boundaries. For metric 9, the number of piscivores (P), the range 4 to 8, was fairly similar for all of the water body types and bridged the boundaries of the reference conditions.

For Metric 2, the number of indicator species, the metric value range across all water body types was 1 to 3, and this metric showed the greatest disparity from the reference condition boundaries with none of waters bodies recording anywhere near even the lower reference condition boundary value of 7.2 indicator species. This metric has some notable limitations in that the indicator species may be under-represented if actual sampling times mismatch the different migratory periods of the different indicator species. Indeed, there appears to be a sampling bias against the indicator species as catches of most migratory species are generally small with many seemingly absent, yet it is known from upstream fishery catches that some species, such as salmon and sea trout, run up into rivers that feed into most of the representative transitional waters (FRS, 2007, Marine Scotland, 2019). Similarly, for the lampreys, while only a few river lampreys were captured from the Forth Estuary, other investigations in upstream fresh waters indicate the occurrence of both river and sea lampreys in tributary rivers of the representative transitional waters (Ecological Research Associates, 2005; O'Reilly *et al.*, 2016; O'Reilly & Morrison, 2018) which must have made migratory passage through the respective transitional water. The TFCI only permits inclusion of data collected from the actual surveyed transitional water. Were such upstream fishery information on the presence of salmonids or lampreys to be incorporated into the TFCI, then the Metric 2 scores could change significantly with a consequent change to the final classification result.

Another shortcoming of Metric 2 is that the presence alone of indicator species does not provide a full picture of the ecological status of these important species. Other studies show that migratory fish in particular may be in real decline due to pressures outwith the transitional water – either upstream in the freshwaters or in coastal or offshore marine waters during their migrations (Malcolm *et al.*, 2010). Both salmon and sea trout, for example, are known to be in decline throughout Scotland and it is suspected that factors affecting their growth and survival at sea may be an important contributor (Ashley, 2019; Kettle-White, 2018; Middlemas, 2019; Reynolds, 2004; Todd *et al.*, 2008; Todd, 2014).

Lamprey populations are less well studied than those of salmonids, but both sea lamprey and river lamprey also appear to have suffered declines in Scotland, although the river lamprey is now considered to have recovered significantly (Maitland *et al.*, 2015; Hume, 2018). There has also been a drastic decline of the European eel populations throughout the whole of Europe, with young glass eel recruitment falling by more than 90% in the 1980s. The European Commission has initiated an Eel Recovery Plan (Bevaqua *et al.*, 2009) to try to return the European eel stock to more sustainable levels and an Eel Management Plan has been produced for Scotland (DEFRA, 2010). Whilst riverine eels are subject to human pressures including overfishing, habitat destruction, migration barriers such as weirs or invasive swim-bladder parasites, recent modelling studies have suggested that ocean current dynamics in the North Atlantic may have caused the major recruitment failures in Europe (Eizaguirre & Baltazar-Soares, 2014; Baltazar-Soares *et al.*, 2014).

Other indicator species such as the smelt (or sparling) and the allis and twaite shads, which may have been relatively widespread in historical times, now have only very limited distributions in Scotland. The smelt is presently restricted to the Tay, Forth and Cree estuaries (Maitland & Lyle, 1996) and the shads to the Solway Firth region (Maitland & Lyle, 2005). Finally, the European sturgeon is included as an indicator species, although it is critically endangered with only a small

population clinging on in the Gironde basin in south-west France (Council of Europe, 2018) and only the very occasional vagrant turns up in British waters. This sturgeon may have spawned in the Severn and Thames in historical times, but it is uncertain if it ever spawned in Scottish waters.

A new tool for assessing transitional water fish communities, the Estuarine Multi-metric Fish Index (EMFI), was developed by Kelly & Harrison (2013) based on their studies of fish communities throughout Ireland. The EMFI is similar to the TFCI in that it is a multi-metric tool that assesses the four community characteristics: species diversity/composition, species abundance, estuarine utilisation, and trophic integrity and also compares metric values against defined reference conditions. However, it incorporates 14 metrics, including the relative abundances of estuarine residents, marine migrants, zoobenthivores, and piscivores. The investigations by Harrison & Kelly (2013) found a relationship between species richness and estuary size, so estuaries are categorised by their size and the various species richness scores adjusted accordingly. The tool also includes a metric for the number of introduced species, which in Ireland could include freshwater fish such as dace (*Leuciscus leuciscus*), chub (*Squalius cephalus*) and roach entering the upper reaches of estuaries. Similar introduced freshwater species also occur in Scotland, but in recent years there has also been records of non-native Pacific pink salmon (*Oncorhynchus gorbuscha*) passing through some of Scotland's estuaries and up into its rivers (BBC, 2019). A practitioner's guide for the application of the EMFI was issued by WFD-UKTAG (2014b) and the tool has now been intercalibrated (Lepage *et al.,* 2016; Harrison *et al.*, 2018; European Commission, 2018). The EMFI appears to offer an improved assessment tool and it would clearly be beneficial to test it on the Scottish data and derive new EMFI Scottish reference conditions with the aim of introducing it to Scotland for future monitoring.

It is unfortunate that political upheaval in the U.K. has changed priorities and cast some doubt over the long term commitment to the standards and monitoring requirements of the EU Water Framework Directive. Nevertheless, the directive sparked the production of the first proper semi-quantitative assessment tools for transitional water fish in the U.K. and Ireland, which are also comparable with similar tools elsewhere in Europe. A set of reference conditions for Scottish transitional water fish communities was derived for the first time. Whilst the assessment tools may be subject to some refinement, or review of their reference condition baselines, they will continue to provide an effective approach for monitoring change in transitional water fish communities, whether due to local anthropogenic factors or perhaps also long term impacts from climate change.

ACKNOWLEDGEMENTS

Thanks are due to the crews of the SEPA survey vessel *Sir John Murray* and the Marine Scotland survey vessel *Alba na Mara* for undertaking various sampling operations. Numerous scientists have assisted with field surveys over many years including Marie Russell (Marine Science, Scotland) and SEPA marine ecologists Lex Pearce, Kirsty Allen, Shelley Reid, Laura Bush, Adrian Moore, Nick Cross, Ryan Eustace, and Emma Priestley. Colleagues on the UK-WFD Transitional Waters Fish Task Team, including Steve Coates and Adam Waugh (both Environment Agency, England), and Trevor Harrison (DAERA, Northern Ireland), have provided valuable guidance on sampling methods and strategies.

REFERENCES

ADRIS (1994). *ADRIS Estuary Classification Scheme, 1994*. Association of Directors and River Inspectors for Scotland. Internal document produced for the River Purification Boards of Scotland and adopted by SEPA in 1996.

Angus, S. (2016). Scottish saline lagoons: Impacts and challenges of climate change. *Estuarine Coastal and Shelf Science* 198. https://doi.org/10.1016/j.ecss.2016.07.014

Ashley, K. (2019). *Wild Salmon*. Scottish Parliament Information Centre briefing, SB 19-48. https://digitalpublications.parliament.scot/Research Briefings/Report/2019/8/19/Wild-Salmon Accessed 10th November 2020.

Baltazar-Soares, M., Biastoch, A., Harrod, C., Hanel, R., Marohn, L., Prigge, E. *et al.* (2014). Recruitment collapse and population structure of the European Eel shaped by local ocean current dynamics. *Current Biology* 24, 104-108. https://doi.org/10.1016/j.cub.2013.11.031

BBC (2009). Swordfish find shocks Alloa fisherman. http:/news.bbc.co.uk/1/hi/Scotland/Tayside and central/8292805.stm

BBC (2019). Invasive Pacific pink salmon found in Scottish rivers. https://www.bbc.co.uk/news/uk-scotland-highlands-islands-49482634 Accessed 10th November 2020.

Bevaqua, D., Melia, P., Crivelli, A., Gatto, M., De Leo, G.A. (2009). Assessing management plans for the recovery of the European Eel: A need for multi-objective analysis. *American Fisheries Society Symposium* 69, 637-647.

Coates, S.A., Colclough, S.R., Robson, M. & Harrison, T.D. (2004). *Development of an Estuarine Classification Scheme for the Water Framework Directive. Phase 1 & 2 - Transitional Fish Component*. R&D Technical Report E1-131/TR. Environment Agency, Bristol.

Coates, S., Waugh, A., Anwar, A. & Robson, M. (2007). Efficacy of a multi-metric fish index as an analysis tool for the transitional fish component of the Water Framework Directive. *Marine Pollution Bulletin* 55, 225-240. https://doi.org/10.1016/j.marpolbul.2006.08.029

Council of Europe (2018). *Pan-European Action Plan for Sturgeons*. Prepared by the World Sturgeon Conservation Society and WWF. Convention on the Conservation of European Wildlife and Natural

Habitats. Standing Committee, 38th meeting, Strasbourg, 27-30 November 2018, TVPS/Inf(2018)6. https://rm.coe.int/pan-european-action-plan-for-sturgeons/16808e84f3 Accessed 10th November 2020.

DEFRA (2010). *Eel Management Plans for the United Kingdom.* Scotland River Basin District. Department for the Environment, Food and Rural Affairs. www.gov.scot/publications/eel-management-plan

Edwards, A. & Sharples, F. (1986). *Scottish Sea Lochs: A Catalogue*. Scottish Marine Biological Association, Dunstaffnage Marine Research Laboratory.

Edwards, R. (1989). Lone sparling brings Forth hope. *Scotland on Sunday*, 10th September.

Eizaguirre, C. & Baltazar-Soares, M. (2014). Rise and fall of eel numbers linked to ocean currents. *The Conversation*, 16th Jan. https://theconversation.com/rise-and-fall-of-eel-numbers-linked-to-ocean-currents-21869 Accessed 10th November 2020.

Elliott, M. & Dewailly, F. (1995). The structure and components of European estuarine fish assemblages. *Netherlands Journal of Aquatic Ecology* 29, 397-417. https://doi.org/10.1007/BF02084239

Elliott, M. & Griffiths, A.H. (1986). Mercury contamination in components of an estuarine ecosystem. *Water Science and Technology* 18, 161-170. https://doi.org/10.2166/wst.1986.0192

Elliott, M. & Griffiths, A.H. (1987). Contamination and effects of hydrocarbons on the Forth ecosystem, Scotland. *Proceedings of the Royal Society of Edinburgh* 93B, 327-342. https://doi.org/10.1017/S0269727000006783

Elliott, M., Griffiths, A.H. & Taylor, C.J.L. (1988). The role of fish studies in estuarine pollution assessment. *Journal of Fish Biology* 33A, 51-61. https://doi.org/10.1111/j.1095-8649.1988.tb05558.x

Elliott, M. & Hemingway, K. (2002). *Fishes in Estuaries*. Blackwell Science Ltd., Oxford. https://doi.org/10.1002/9780470995228

Elliott, M., O'Reilly, M.G. & Taylor, C.J.L. (1990). The Forth Estuary: a nursery and overwintering area for North Sea fishes. *Hydrobiologia,* 195, 89-103. https://doi.org/10.1007/BF00026816

Elliott, M. & Taylor, C.J.L. (1989). The structure and functioning of an estuarine/marine fish community in the Forth estuary, Scotland. *Proceedings of the 21st European Marine Biology Symposium, Gdansk, 14-19 September 1986*, 227-240.

Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G. & Harrison, T.D. (2007). The guild approach to categorizing estuarine fish assemblages: a global review. *Fish and Fisheries* 8, 241-268.

Ecological Research Associates (2005). *National Lamprey Survey of Scotland.* Report to Scottish Natural Heritage, (ROAME No. F02AC602).

European Commission (2013). Commission Decision (2013/480/EC) of 20 September 2013 establishing, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, the values of the Member State monitoring system classifications as a result of the intercalibration exercise and repealing Decision 2008/915/EC. *Official Journal of the European Union*, L 266/1. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013D0480&qid=1589479209675&from=EN Accessed 6th June 2020.

European Commission (2018). Commission Decision (EU) 2018/229 of 12 February 2018 establishing, pursuant to Directive 2000/60/EC of the European Parliament and of the Council, the values of the Member State monitoring system classifications as a result of the intercalibration exercise and repealing Commission Decision 2013/480/EU. *Official Journal of the European Union*, L 47/1. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1589479209675&uri=CELEX:32018D0229 Accessed 6th June 2020.

European Union (2000). Parliament and Council Directive 2000/60/EC of 23rd October 2000. Establishing a Framework for Community Action in the Field of Water Policy. *Official Journal PE-CONS 3639/1/00 REV 1*. Brussels: European Union.

Franco, A., Elliott, M., Franzoi, P. & Torricelli, P. (2008). Life strategies of fish in European estuaries: the functional guild approach. *Marine Ecology Progress Series* 354-219-228. https://doi.org/10.3354/meps07203

FRS (2003). *Decline & Recovery of Salmon in the Central Belt of Scotland.* Fisheries Research Services, FRS Freshwater Laboratory, Pitlochry,. https://www2.gov.scot/Uploads/Documents/Decline%20poster.pdf Accessed 10th November 2020.

FRS (2007). *Statistical Bulletin. Scottish Salmon and Sea Trout catches, 2006*. Fisheries Series, No. Fis/2007/1, September 2007. Fisheries Research Services, FRS Freshwater Laboratory, Pitlochry.

Gardiner, R. & Armstrong, J. (1996). *Migratory Salmonid Fishes in the River Kelvin: Historical Backgound, Present Situation and Opportunities for Improvement*. Fisheries Research Services Report, 4/96.

Greenstreet, S.P.R., Rossberg, A.G., Fox, C.J., Le Quesne, W.J.F., Blasdale, T., Boulcott, P. *et al.* (2012). Demersal fish biodiversity: species-level indicators and trends-based targets for the Marine Strategy Framework Directive. *ICES Journal of Marine Science* 69, 1789–1801. https://doi.org/10.1093/icesjms/fss148

Greenwood, M.F.D. (2008a). Trawls and cooling water intakes as estuarine sampling tools: trends in relative abundance and length selectivity. *Estuarine, Coastal and Shelf Science* 76, 121-130. https://doi.org/10.1016/j.ecss.2007.06.008

Greenwood, M.F.D. (2008b). Fish mortality by impingement on intake screens of Britain's largest direct-cooled power station. *Marine Pollution Bulletin* 56, 723-739. https://doi.org/10.1016/j.marpolbul.2007.12.008

Greenwood, M.F.D., Hill, A.S. & McLusky, D. (2002). Trends in abundance of demersal fish populations of

the lower Forth Estuary, Scotland from 1982-2001. *Journal of Fish Biology* 61A, 90-104. https://doi.org/10.1006/jfbi.2002.2070

Greenwood, M.F.D. & Hill, A.S. (2003). Temporal, spatial and tidal influences on demersal fish abundance in the Forth Estuary. *Estuarine, Coastal and Shelf Science* 58, 211-225. https://doi.org/10.1016/S0272-7714(03)00071-4

Greenwood, M.F.D. & Maitland, P.S. (2009). Long-term changes in fish-assemblage composition from cooling-water intake screens in the Forth Estuary, Scotland, UK. *JMBA2 - Biodiversity Records*, 2, Jan.2009, e8. https://doi.org/10.1017/S1755267208000080

Griffiths, A.H. (1987). Water Quality of the estuary and Firth of Forth, Scotland. *Proceedings of the Royal Society of Edinburgh* 93B, 303-314. https://doi.org/10.1017/S026972700000676X

Haig, A.J.N. (1986). Use of the Clyde Estuary and Firth for disposal of effluents. *Proceedings of the Royal Society of Edinburgh* 90B, 393-405. https://doi.org/10.1017/S026972700000511X

Hammerton, D. (1986). Cleaning the Clyde – a century of progress? *Journal of the Operational Research Society* 37, 911-921. https://doi.org/10.1057/jors.1986.154

Hammerton, D. (1997). The restoration of the Clyde River. In: Laenen, A. & Dunnette, D.A. (Editors). *River Quality – Dynamics and Restoration*, pp. 423-434. CRC Press, Boca Raton, Florida, U.S.A. https://doi.org/10.1201/9780203740576-39

Harrison, T.D. & Kelly, F.L. (2013). Development of an estuarine multi-metric fish index and its application to Irish transitional waters. *Ecological Indicators* 34, 494-506. https://doi.org/10.1016/j.ecolind.2013.06.018

Harrison, T., Kelly, F., Lepage, M. & Sales Herrero, F. (2018). *Intercalibration of a New Fish Ecological Assessment Method*. Transitional Waters North East Atlantic Geographical Intercalibration Group, JRC Technical Reports, European Commission. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC115083/jrc115083_tw_neagig._fish_ecological_assesment_methods-new_method-1.pdf Accessed 10th November 2020.

Henderson, A.R. & Hamilton, J.D. (1986). The status of fish populations in the Clyde Estuary. *Proceedings of the Royal Society of Edinburgh* 90B, 157-170. https://doi.org/10.1017/S0269727000004966

Hume, J.B. (2018). A review of the geographic distribution, status and conservation of Scotland's lampreys. *The Glasgow Naturalist* 26(4), 67-76.

Kettle-White, A. (2018). *Turning the Tide for Scotland's Sea Trout*. https://scottishwildlifetrust.org.uk/2018/12/turning-the-tide-for-scotlands-sea-trout/ Accessed 10th November 2020.

Leatherland, T.M. (1987). The estuary and Firth of Forth, Scotland: uses and aims. *Proceedings of the Royal Society of Edinburgh* 93B, 285-297. https://doi.org/10.1017/S0269727000006746

Lepage, M., Briene, J., Van den Bergh, E., Mosch, E.C., Scholle, J., Kelly, F. *et al.* (2013). *Intercalibration of Biological Elements for Transitional and Coastal Water Bodies*. North East Atlantic GIG: Transitional Waters – Fish. European Commission Intercalibration Technical Report.

Lepage, M., Harrison, T., Breine, J., Cabral, H., Coates, S., Galván, C. *et al.* (2016). An approach to intercalibrate ecological classification tools using fish in transitional water of the North East Atlantic. *Ecological Indicators* 67, 318–327. https://doi.org/10.1016/j.ecolind.2016.02.055

Mackay, D.W., Tayler, W.K. & Henderson, A.R. (1978). The recovery of the polluted Clyde Estuary. *Proceedings of the Royal Society of Edinburgh* 76B, 135-152. https://doi.org/10.1017/S0269727000002839

Mackay, D.W. & Doughty, C.R. (1986). Migratory salmonids of the Estuary and Firth of Clyde. *Proceedings of the Royal Society of Edinburgh* 90B, 479-490. https://doi.org/10.1017/S0269727000005170

Maitland, P.S. & Herdson, D. (2009). *Key to the Marine and Freshwater Fishes of Britain and Ireland.* Environment Agency, Bristol.

Maitland, P.S. & Lyle, A.A. (1990). Conservation of Sparling and other fish in Scotland. *Journal of the Edinburgh Natural History Society* 1-2, 16-18.

Maitland, P.S. & Lyle, A.A. (1996). The smelt *Osmerus eperlanus* in Scotland. *Freshwater Forum* 6, 57-68.

Maitland, P.S. & Lyle, A.A. (2005). Ecology of Allis shad *Alosa alosa* and Twaite shad *Alosa fallax* in the Solway Firth, Scotland. *Hydrobiologia* 534, 205–221. https://doi.org/10.1007/s10750-004-1571-1

Maitland, P.S., Renaud, C.R., Quintella, B.R., Close, D.A. & Docker, M.F. (2015). Conservation of native lampreys. In: Docker, M.F. (Editor). *Lampreys: Biology, Conservation and Control. Vol. 1*, pp. 376-428. Springer Publishing, New York, U.S.A. https://doi.org/10.1007/978-94-017-9306-3_8

Malcolm, I.A., Godfrey, J. & Youngson, A.F. (2010). Review of migratory routes and behaviour of Atlantic Salmon, Sea Trout, and European Eel in Scotland's coastal environment: Implications for the development of marine renewables. *Scottish Marine and Freshwater Science* 1(14), 1-77.

Marine Scotland (2019). *Salmon and Sea Trout Fishery Statistics: 2018 Season – Reported Catch and Effort by Method*. DOI: 10.4789/12206-1. Retrieved from https://scotland.shinyapps.io/sg-salmon-sea-trout-catch/ Accessed 10th November 2020

McInerny, C.J. & Hoey, K. (2021). Unusual aquatic vertebrates in the Firth of Forth, Scotland, during 2020: swordfish and northern bottlenose whales. *The Glasgow Naturalist* 27(3), 97-98. https://doi.org/10.37208/tgn27308

McLusky, D.S. (1987). The Natural Environment of the Estuary and Firth of Forth. Introduction. *Proceedings of the Royal Society of Edinburgh* 93B, vii-x. https://doi.org/10.1017/S0269727000006837

Middlemas, S. (2019). Understanding the decline of Atlantic salmon catches in Scotland. British Ecological Society/News and Opinion,

https://www.britishecologicalsociety.org/understanding-decline-atlantic-salmon-catches-scotland/ Accessed 10th November 2020.
O'Reilly, M., Nowacki, S. & Elliott, M. (2016). A Citizen Science approach to monitoring migratory lampreys under the Water Framework Directive, with some new accounts of sea lampreys (*Petromyzon marinus*) from south west Scotland. *The Glasgow Naturalist* 26(2), 102-105.
O'Reilly, M. & Morrison, S. (2018). First record of river lampreys (*Lampetra fluviatilis*) in the River Garnock, Ayrshire. *The Glasgow Naturalist* 26(4), 92-93.
Pomfret, J.R., Elliott, M., O'Reilly, M.G. & Phillips, S. (1991). Spatial and temporal patterns in the fish communities in two UK North Sea estuaries. In: Elliott, M. & Ducrotoy, J.P. (Editors). *ECSA 19 Symposium. Estuaries and Coasts: Spatial and Temporal Intercomparisons*, pp. 277-284. Olsen & Olsen, Fredensborg, Denmark.
Poxton, M.G. (1987). Fishery studies in the estuary and Firth of Forth. *Proceedings of the Royal Society of Edinburgh* 93B, 495-508. https://doi.org/10.1017/S0269727000006904
Reynolds, J. (2004). Warning of 'dramatic decline' in Scottish sea trout. *The Scotsman* 23rd August.
Todd, C. (2014). Shrinking wild salmon starve at sea as North Atlantic warms. *The Conversation*, 21st January. https://theconversation.com/shrinking-wild-salmon-starve-at-sea-as-north-atlantic-warms-22264 Accessed 10th November 2020.
Todd, C.D., Hughes, S.H., Marshall, C.T., MacLean, J.C., Lonergan, M. & Biuw, E.M. (2008). Detrimental effects of recent ocean surface warming on growth condition of Atlantic salmon. *Global Change Biology* 14, 958-970. https://doi.org/10.1111/j.1365-2486.2007.01522.x
WFD CIS (2003a). *Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 5. Transitional and Coastal Waters – Typology, reference conditions and classification systems.* Produced by Working Group 2.4 COAST. Directorate General Environment of the European Commission, Brussels, Belgium.
WFD CIS. (2003b). *Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 10. Rivers and Lakes – Typology, reference conditions and classification systems*. Produced by Working Group 2.3 REFCOND. Directorate General Environment of the European Commission, Brussels, Belgium.
WFD-UKTAG (2003). *Guidance on Typology for Coastal and Transitional Waters of the UK and Republic of Ireland* (Final). Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG). https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Marine%20typology_Final_281003.pdf Accessed 6th June 2020.
WFD-UKTAG (2012). *Practitioners Guide to the Transitional Fish Classification Index (TFCI) Water Framework Directive: Transitional Waters*. Version 07, 301112. https://www.wfduk.org/sites/default/files/Media/Environmental%20standards/Annex%2021%20Transitional%20waters%20Fish%20TFCI.pdf Accessed 6th June 2020.
WFD-UKTAG (2014a). *UKTAG Transitional Water Assessment Method – Fish fauna. Transitional Fish Classification Index.* Water Framework Directive – United Kingdom Technical Advisory Group (WFD-UKTAG). https://www.wfduk.org/sites/default/files/Media/Characterisation%20of%20the%20water%20environment/Biological%20Method%20Statements/TW%20Fish%20UKTAG%20Method%20Statement.pdf Accessed 6th June 2020.
WFD-UKTAG (2014b). *Practitioners Guide to the Estuarine Multi-metric Fish Index (EMFI) Water Framework Directive: Transitional Waters*. Version 01 180814.
Whitfield, A.K. & Elliott, M. (2002). Fishes as indicators of environmental and ecological changes within estuaries: A review of progress and some suggestions for the future. *Journal of Fish Biology* 61A, 229-250. https://doi.org/10.1111/j.1095-8649.2002.tb01773.x

The Glasgow Naturalist (2021) Volume 27, Part 3, 68-71

SUPPLEMENT (Part 2): ON THE WILD SIDE REVISITED: 200 YEARS OF WILDLIFE IN THE GLASGOW BOTANIC GARDENS

https://doi.org/10.37208/tgn27325

On the Wildside 2: what the Glasgow Botanic Gardens *Wildside* project has achieved and what remains to be done

R.B. Weddle[1] and J.R. Downie[2]

[1]89 Novar Drive, Glasgow G12 9SS
[2]School of Life Sciences, Graham Kerr Building, University of Glasgow, Glasgow G12 8QQ

[1]E-mail: richard@canto.plus.com

When Downie & Forster (2019) introduced the five papers constituting the first part of the *On the Wildside Revisited* supplement, the context was twofold. First, the work was a follow-up to biodiversity surveys carried out in the late 1990s, about two decades ago. Second, the new surveys were a contribution to the celebratory events associated with the bicentenary in 2017 of the Glasgow Botanic Gardens, Scotland. Introducing this second set of papers (two full papers and six short notes) presents a good opportunity to reflect on what the whole process has achieved and what still needs to be done.

We should define the area covered by the surveys. This was not done for the original *On the Wildside* supplement, published in two parts in separate issues of *The Glasgow Naturalist* (Hancock, 1998, 1999). However, close reading of Macpherson (1998) on the plants shows that recording extended some way beyond the Gardens' gates into the area along the River Kelvin. The map (Fig. 1) shows the Gardens, the river and the vegetated river-sides from the Garrioch Flint Mill on the southeast to the disused railway bridge adjacent to Kelvinside Allotments. The biological records we report on come primarily from the Gardens *sensu stricto* but do extend into this riverine area. Fig. 1 includes dots showing the distribution of records.

Fig. 1. Map of Glasgow Botanic Gardens, Scotland and surrounding area. The dots show the distribution of records; those falling in the surrounding urban area represent records with rather wayward National Grid References.

What species are included? Glasgow Botanic Gardens hold a large variety of plant species and varieties brought from around the world, both under cover and in the open, depending on their hardiness to Scottish weather. The intention of the *Wildside* project has been to record the plants and animals living in the wild state in this area, rather than the specially cultivated species. However, cultivated species can reproduce and spread, and Macpherson (1998) listed both native wild plants and aliens, many of them species that are cultivated in the Gardens but which had escaped beyond their original sites. Gray's paper (1998) on the trees went further, listing and measuring not only wild trees beyond the Gardens' gates but also the trees planted as part of the Gardens' collections.

What of the animals? When we describe an animal species as being present in the Gardens, or observed there, what does that imply? In the case of migratory birds, they may simply be flying over: should they be included in the species lists? Such birds are noted in this issue (McInerny, 2021), but are only included in the database of records when they have been observed on the ground, or on vegetation, or on water in the project area. And what of domestic animals? The mammal species list (Sutcliffe, 2019) includes domestic dogs and cats (a feral one), and even a likely pet rabbit (earlier records may have been of wild ones), but we have excluded these from the records database on grounds of consistency. Similarly, the goldfish and tropical freshwater fish in ponds in the glasshouses are not included in the database.

And what of the organisms that are neither plants nor animals? On the basis of Whittaker's Five Kingdom system (Whittaker, 1969), biologists recognise five major groups of organisms: plants, animals, fungi, protists (single-celled organisms with nuclei) and prokaryotes (single-celled organisms lacking nuclei, such as bacteria). As we shall see, some natural historians have an enthusiastic interest in fungi, and they are well recorded. However, protists and prokaryotes are groups needing more specialised expertise, and have been much less recorded.

The complete records list for the Gardens (January 2021; www.gnhs.org.uk/biodiversity/GBG_splist.pdf) shows 1,384 species and 4,454 records, some species having been recorded more than once. The list also shows the year of first and most recent recording, and the number of times each species has been recorded (this is distinct from the relative abundance of the species, as each record could be of multiple individuals). Fig. 2 sorts the records into time periods. Records began long before the *Wildside* project, but were sparse in the 19th century (73 records) and accelerated only in the 21st century, 78% of records having been made since the year 2000. This pattern clearly has little to do with the arrival of new species into the area, though there has been some of that, but more to do with an increasing interest in recording urban biodiversity, and the expertise and enthusiasm of particular recorders. A nice expression of the difficulties in increasing our records of some species

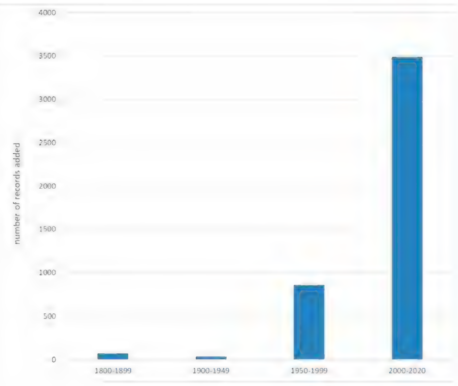

Fig. 2. The number of records of organisms in Glasgow Botanic Gardens generated over the centuries.

comes from the referee of the short note on a small leaf-hopper (Weddle, 2021): "I fear that the scarcity of records… in Scotland and northern England is a reflection of several factors: the scarcity of entomologists in those regions, especially ones who regularly look at this particular group of insects, and perhaps a reluctance to dissect small pale species such as this species that look very similar externally and differ on the basis of rather minor internal features."

Fig. 3 and Fig. 4 sort the species into 16 separate groups, the two largest being vascular plants (over 400) and moths (230). Group and species accounts amongst the 13 papers and short notes published in the *Wildside Revisited* series to date (2019 and 2021) comment on notable recent additions and apparent losses. Overall, it is only possible to make such comments on organism groups that are surveyed frequently and where we have relevant expertise.

We feel that it is worthwhile here to draw attention to the major gaps, hoping that they may be filled in future. Protists are heavily under-recorded, with single records only for protozoa and slime moulds. Both groups require expertise, but could be rewarding: an online account (Featherstone, 2012) of slime moulds in a single Scottish forest reports over 70 species. Prokaryotes require even more specialised knowledge, but many cause diseases of plants and it should be possible to record some of them. Freshwater habitats in the study area have been little sampled for records, although adult insects emerging from aquatic larvae feature strongly in the database (for example, 31 caddis flies; three dragonflies or damselflies; nine mayflies; but no stoneflies). The records we do have rely heavily on the moth traps which also capture other flying insects. In the glasshouse ponds, the invasive tropical snail *Melanoides tuberculatus* is recorded, since it was not introduced deliberately. However, there may be other freshwater invertebrates in the ponds, so far unnoticed.

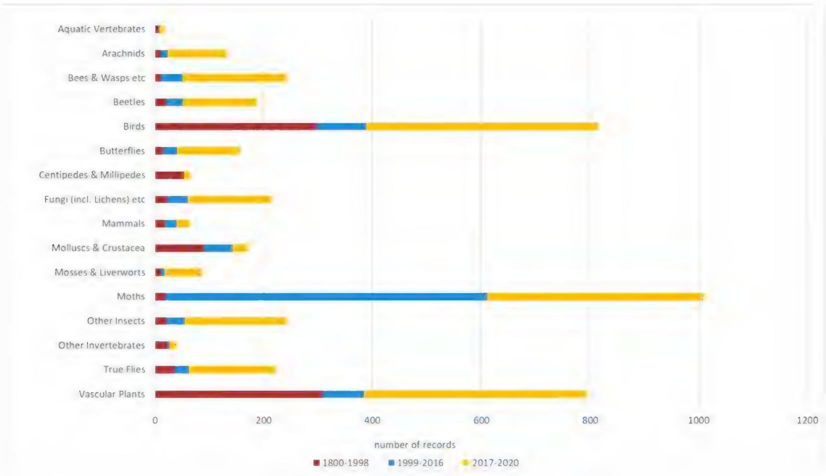

Fig. 3. The number of records for each organismal group in Glasgow Botanic Gardens before the 1999 *Wildside* reports, between then and the bicentenary of the Gardens in 2017, and during the *Wildside Revisited* project to date.

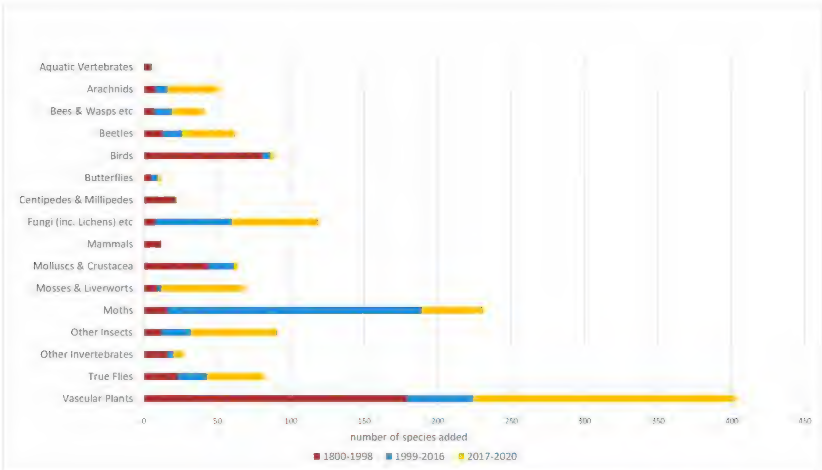

Fig. 4. The number of species within each organismal group in Glasgow Botanic Gardens first recorded before the 1999 *Wildside* reports, between then and the bicentenary of the Gardens in 2017, and during the *Wildside Revisited* project to date.

Downie & Forster (2019) expected that the second batch of *Wildside Revisited* papers would be published in 2020, but this was not to be. Even the current set is not the end. We expect papers on mosses and liverworts, vascular plants, and arachnids to appear in due course, and on other topics once worthwhile new observations are made and some existing specimens have been identified. The preparation of good quality papers cannot be rushed, especially when the contributors are volunteers.

We hope that readers will feel that these contributions are worth the wait, and that the new information accumulated will not be the end of the process. The 'wildside' of the Gardens will be worth visiting repeatedly in future.

REFERENCES

Downie, J.R. & Forster, S.J. (2019). On the Wildside 2: the natural history of the Glasgow Botanic Gardens revisited. *The Glasgow Naturalist* 27(1), 49. https://doi.org/10.37208/tgn27108

Featherstone, A.W. (2012). In search of slime moulds. https://alanwatsonfeatherstone.com/in-search-of-slime-moulds/ Accessed 26th January 2021.

Gray, R.K.S. (1998). Trees of Glasgow Botanic Gardens. *The Glasgow Naturalist* 23(3), 49-52.

Hancock, E.G. (Editor) (1998). On the Wildside: the natural history of the Glasgow Botanic Gardens. *The Glasgow Naturalist* 23(3), 40-56.

Hancock, E.G. (Editor) (1999). On the Wildside: the natural history of the Glasgow Botanic Gardens. *The Glasgow Naturalist* 23(4), 59-64.

McInerny, C.J. (2021). The birds of Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(3), 72-76. https://doi.org/10.37208/tgn27310

Macpherson, P. (1998). Plants growing in a wild state. *The Glasgow Naturalist* 23(3), 44-49.

Sutcliffe, R. (2019). Non-avian vertebrates in Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(1), 69-70. https://doi.org/10.37208/tgn27113

Weddle, R.B. (2021). *Edwardsiana alnicola* (Hemiptera: Cicadellidae): a leaf-hopper new to Scotland, in Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(3), 92. https://doi.org/10.37208/tgn27317

Whittaker, R.H. (1969). New concepts of kingdoms of organisms. *Science* 163, 150-159. https://doi.org/10.1126/science.163.3863.150

 https://doi.org/10.37208/tgn27310

The birds of Glasgow Botanic Gardens

C.J. McInerny

School of Life Sciences, University of Glasgow, Glasgow G12 8QQ

E-mail: chris.mcinerny@glasgow.ac.uk

ABSTRACT
A summary is presented of the bird species recorded in Glasgow Botanic Gardens, Scotland for the period 1998-2020. Comparisons are made against similar bird lists made over the past 100 years, with trends and changes described and discussed. A few observations of unusual and rarely seen species are included.

INTRODUCTION

This paper is one of a series describing the wildlife of Glasgow Botanic Gardens (GBG), and how it has changed over the years (Downie & Forster, 2019). The Gardens contain a number of habitats supporting different types of birds, in an otherwise largely urbanised area of a major city. This has resulted in a wide range of species being recorded over the years and these have been tabulated into bird lists. Such lists have been compiled by various authors, summarised by Grist & McCallum (1998), who completed their own bird list for the years 1994-1997. Other data about the birds observed in GBG were provided by Richard Weddle through the Glasgow Museums Biological Record Centre:
http://www.gnhs.org.uk/biodiversity/GBG_splist.pdf

The author of this contribution lives within 300 m of GBG and has visited the Gardens regularly from 1998 to 2020, averaging 2-3 visits per week. On each visit, bird numbers and species were noted. The compilation of these observations resulted in the most recent bird list shown in Table 1. Because this list shows the binomial names for each species, these have not been used in the main text. The 1998-2020 list has been tabulated with those of Grist & McCallum (1998) to allow comparisons and to reveal trends and changes.

RESULTS

Wildfowl

Neither the greylag goose nor pink-footed goose were noted in previous lists. In recent years pink-footed geese have been seen most springs during March and April when migrating flocks pass north on their way to Arctic breeding grounds, often first apprehended by their far-reaching honking calls. More rarely, returning flocks were noted in September and October. Greylag geese have also been recorded flying over but are more irregular. Much rarer, whooper swans have been seen passing just once: a flock of up to 80 on 29th March 2009; these too were migrating north. Another single was present in September 2017 on the River Kelvin (Forster, 2019).

The goosander has become a common breeding species along the River Kelvin in recent years and flocks of up to 12 birds have been recorded in winter. This increase follows its protection and consequent population growth across Scotland (Forrester *et al*., 2007). In the past, goosanders were controlled as they took fish in areas with angling interests.

Heron, cormorant and gannet

The rarest bird recorded at GBG, in a Scottish context, was an immature night-heron that remained from early November to 13th December 1926, being just the tenth national observation (Paterson, 1927). The night-heron was found “on a tree on the steep sloping bank of the Kelvin [and] resting on one leg with its head drawn back and its feathers bunched out and, with its crow-like head and moderately long and slightly decurved bill, it made a notable silhouette.”

Cormorants are seen regularly flying overhead or foraging in the River Kelvin, sometimes in groups of up to three, at all times of the year. Just once, in September 2010, a juvenile gannet, a marine species, was watched following the course of the river.

Birds of prey

An addition to the list is the buzzard, with birds occasionally flying over the site. This reflects the increase in numbers and range of the species over the past 30 years throughout Scotland (Forrester *et al*., 2007). Pairs nest in east and north Glasgow with the birds seen at GBG likely deriving from these.

Another new bird of prey observed irregularly at GBG is the peregrine. These falcons have colonised urban areas, nesting in Glasgow on suitable tall buildings, hunting feral pigeons present throughout the city and are occasionally seen flying over.

Shorebirds

The oystercatcher and common sandpiper have both been recorded along the River Kelvin, and are new additions to the GBG bird list. These are summer passage migrants moving upstream to inland breeding areas. In the case of the oystercatcher they are usually heard while flying through, sometimes at night.

		Trend	1894-1901	1966-1985	1994-1997	1998-2019 status
Greylag goose	*Anser anser*	↑	-	-	-	P
Pink-footed goose	*Anser brachyrhynchus*	↑	-	-	-	P
Mute swan	*Cygnus olor*		✓	✓	✓	RLB
Whooper swan	*Cygnus cygnus*		-	-	-	PV
Mallard	*Anas platyrhynchos*		-	✓	✓	RB
Pochard	*Aythya ferina*		-	✓	-	-
Tufted duck	*Aythya fuligula*		-	✓	-	PV
Goosander	*Mergus merganser*	↑	-	✓	✓	RB
Pheasant	*Phasianus colchicus*		✓	-	-	-
Little grebe	*Tachybaptus ruficollis*		-	-	-	PV
Night-heron*	*Nycticorax nycticorax*		-	-	-	-
Grey heron	*Ardea cinerea*		-	-	✓	RLB
Cormorant	*Phalacrocorax carbo*		-	-	-	P
Sparrowhawk	*Accipiter nisus*		✓	✓	✓	RB
Buzzard	*Buteo buteo*	↑	-	-	-	RLB
Corncrake	*Crex crex*		✓	-	-	-
Moorhen	*Gallinula chloropus*		✓	✓	✓	RB
Coot	*Fulica atra*		-	✓	-	-
Oystercatcher	*Haematopus ostralegus*		-	-	-	P
Lapwing	*Vanellus vanellus*		✓	-	-	-
Woodcock	*Scolopax rusticola*	↑	-	-	-	W
Snipe	*Gallinago gallinago*		-	✓	-	-
Common sandpiper	*Actitis hypoleucos*		✓	-	-	P
Common gull	*Larus canus*		-	-	-	P
Herring gull	*Larus argentatus*	↑	-	✓	✓	RLB/P
Lesser black-backed gull	*Larus fuscus*	↑	-	✓	✓	RLB/P
Sandwich tern	*Thalasseus sandvicensis*		-	-	-	PV
Common tern	*Sterna hirundo*		-	-	-	PV
Rock dove/feral pigeon	*Columba livia*	↑	-	✓	✓	RB
Stock dove	*Columba oenas*	↑	-	-	-	RB
Woodpigeon	*Columba palumbus*	↑	✓	✓	✓	RB
Collared dove	*Streptopelia decaocto*	↓	-	✓	✓	RLB
Cuckoo	*Cuculus canorus*		✓	-	-	-
Tawny owl	*Strix aluco*		-	✓	✓	RB
Swift	*Apus apus*	↓	✓	✓	✓	SLB/P
Kingfisher	*Alcedo atthis*	↑	-	✓	✓	RB
Great spotted woodpecker	*Dendrocopos major*	↑	-	-	✓	RB
Kestrel	*Falco tinnunculus*		-	✓	✓	PV
Peregrine	*Falco peregrinus*	↑	-	-	-	RLB
Ring-necked parakeet	*Psittacula krameri*	↑	-	-	-	RLB
Magpie	*Pica pica*	↑	✓	✓	✓	RB
Jackdaw	*Coloeus monedula*	↑	✓	-	✓	RLB
Rook	*Corvus frugilegus*	↓	✓	✓	-	-
Carrion crow	*Corvus corone*		✓	✓	✓	RB
Raven	*Corvus corax*	↑	-	-	-	RLB
Waxwing	*Bombycilla garrulus*		-	✓	-	WV
Coal tit	*Periparus ater*					RB
Blue tit	*Cyanistes caeruleus*		✓	✓	✓	RB
Great tit	*Parus major*		✓	✓	✓	RB
Skylark	*Alauda arvensis*		-	-	-	PV
Sand martin	*Riparia riparia*	↑	✓	-	-	LB
Swallow	*Hirundo rustica*		✓	-	-	P
House martin	*Delichon urbicum*		-	-	-	PV
Long-tailed tit	*Aegithalos caudatus*	↑	-	✓	✓	LB
Willow warbler	*Phylloscopus trochilus*	↑	✓	-	-	SLB/P

Chiffchaff	*Phylloscopus collybita*	↑	✓	-	-	SB/P
Wood warbler+	*Phylloscopus sibilatrix*		✓	-	-	PV
Blackcap	*Sylvia atricapilla*	↑	✓	-	-	SB/P
Garden warbler	*Sylvia borin*		✓	-	-	-
Whitethroat	*Sylvia communis*		✓	-	-	-
Firecrest+	*Regulus ignicapilla*		-	-	-	WV
Goldcrest	*Regulus regulus*		-	✓	-	RB
Wren	*Troglodytes troglodytes*		✓	✓	✓	RB
Nuthatch	*Sitta europaea*	↑	-	-	-	RB
Treecreeper	*Certhia familiaris*		✓	✓	✓	RB
Starling	*Sturnus vulgaris*		✓	-	✓	RB
Blackbird	*Turdus merula*		✓	✓	✓	RB
Fieldfare	*Turdus pilaris*		✓	-	-	W
Redwing	*Turdus iliacus*		✓	✓	✓	W
Song thrush	*Turdus philomelos*		✓	✓	✓	RB
Mistle thrush	*Turdus viscivorus*		✓	✓	✓	RB
Spotted flycatcher	*Muscicapa striata*		-	✓	-	-
Robin	*Erithacus rubecula*		✓	✓	✓	RB
Redstart	*Phoenicurus phoenicurus*		✓	-	-	-
Whinchat	*Saxicola rubetra*		-	✓	-	-
Stonechat	*Saxicola rubicola*		✓	-	-	-
Dipper	*Cinclus cinclus*	↑	-	✓	-	RB
House sparrow	*Passer domesticus*	↑	-	✓	✓	RB
Dunnock	*Prunella modularis*		✓	✓	✓	RB
Yellow wagtail	*Motacilla flava*	↓	✓	✓	-	-
Grey wagtail	*Motacilla cinerea*		✓	✓	✓	RB
Pied wagtail	*Motacilla alba*		✓	✓	✓	RLB/W
Meadow pipit	*Anthus pratensis*		-	-	-	P
Chaffinch	*Fringilla coelebs*		✓	✓	✓	RB
Brambling	*Fringilla montifringilla*		-	✓	-	-
Hawfinch+	*Coccothraustes coccothraustes*		-	-	-	PV
Bullfinch	*Pyrrhula pyrrhula*	↑	✓	✓	✓	RB
Greenfinch	*Chloris chloris*		✓	✓	✓	RB
Linnet	*Linaria cannabina*	↓	✓	✓	-	-
Lesser redpoll	*Acanthis cabaret*	↑	-	-	-	W
Crossbill+	*Loxia curvirostra*		-	-	-	PV
Goldfinch	*Carduelis carduelis*	↑	✓	✓	-	RB
Siskin	*Spinus spinus*	↑	-	-	-	W
Corn bunting	*Emberiza calandra*	↓	✓	-	-	-
Yellowhammer	*Emberiza citrinella*	↓	✓	-	-	-
Reed bunting	*Emberiza schoeniclus*	↓	✓	-	-	-

Table 1. Bird species seen in Glasgow Botanic Gardens, Scotland, from 1894 to 2020. The data for the first three columns (1894-1901, 1966-1985 and 1994-1997) are taken from Grist & McCallum (1998). Trends over the period are indicated: ↑= increasing; ↓= decreasing; ✓ = present; - = absent. For 1998-2020 the status codes are: RB = resident breeder; SB = summer breeder; RLB = resident local breeder outside GBG; SLB = summer local breeder outside GBG; W = winter visitor; P = passage migrant; V = vagrant/rare; * seen just once in 1926 (Paterson, 1927); + seen near to GBG. The sequence of species and English names follows the 9th edition of the British List, as published by the British Ornithologists' Union (McInerny *et al.*, 2018).

The woodcock instead is a winter visitor to GBG from breeding areas elsewhere in Scotland or the continent. Birds wintering in Scotland are usually found in wooded and damp areas in the countryside but they can be present in cities during particularly cold weather when the ground freezes and prevents these ground-probing birds from feeding. The winter of 2010/11 was exceptionally cold during December with the River Kelvin icing over: a number of woodcocks were seen along the embankment. A corpse was found of a bird that had flown into a window of the author's house, which is preserved at National Museums Scotland, Edinburgh.

Gulls and terns

No gulls or terns breed in GBG, but both lesser black-backed gulls and herring gulls nest widely throughout Glasgow on roof-tops, and are a common sight in the spring and summer breeding period. Black-headed gulls and common gulls are more irregular, occasionally seen passing through. Much rarer are the common tern and sandwich tern, both of which have been observed flying over once each in spring, in groups of two and three, respectively.

Doves and pigeons

An interesting addition to the breeding list of the Gardens is the stock dove (Fig. 1A), a species of arable and open countryside areas in Scotland (Forrester *et al*., 2007). In this context the discovery of a colony of up to nine nests in a stone wall along the River Kelvin, less than 1 km downstream of GBG, was noteworthy; this is the only known urban colony in Scotland and the U.K. (McInerny, 2018, 2020). Single pairs also breed in tall ivy-clad trees along the River Kelvin, with at least two nests within GBG.

Wood pigeons are conspicuous and common resident breeders. In contrast, the collared dove no longer breeds in the Gardens and is seen rarely, nesting in very small numbers nearby. This is a change in status for the species: Grist & McCallum (1998) noted its natural colonisation of the U.K. since the 1950s and increase in numbers; the trend has now reversed at GBG and across Glasgow, for unknown reasons.

Swift

A species that has shown a marked decline in observations is the swift. During the 1990s it was a frequent summer breeding species in the West End of Glasgow, with birds often heard "screaming" overhead. Now it is largely absent from the area, with just a few passage birds moving to breeding areas elsewhere in Glasgow and Scotland.

Parakeet

An exotic addition to the list in recent times is the ring-necked parakeet. These introduced birds from the Indian subcontinent have been colonizing England for many years with very large numbers now present. Breeding was first confirmed in Scotland during 2016 at Victoria Park, Glasgow, just over 2 km to the west of GBG (McInerny, 2016, 2017), with increasing numbers subsequently elsewhere in Glasgow. At least two groups (four and six birds) have been seen flying over GBG revealed by their loud shrieking call. It seems likely that the species will nest in GBG in the future, as a preferred breeding habitat is suburban parks and gardens.

Woodpecker and nuthatch

Both the great spotted woodpecker and nuthatch now nest regularly in the Gardens. In the case of the nuthatch this reflects a striking range expansion for the species across Scotland in the past 20 years (Forrester *et al*., 2007). The only pair in GBG first arrived in December 2016 and has used the same bat box for nesting in four consecutive years, from 2017-2020 (Fig. 1B,C).

Fig. 1. Two bird species that have recently colonised Glasgow Botanic Gardens, Scotland, and which now breed every year. A. Stock dove (*Columba oenas*), 14th March 2018. These birds use tall ivy-clad trees along the River Kelvin for nest sites, where this individual was photographed. Nuthatch (*Sitta europaea*), male (B) and female (C), 22nd May 2020. This pair raised young in a bat box in the Gardens, which they had used for nesting the previous two years. (Photos: C.J. McInerny)

Corvids and waxwing

Raven and jackdaw numbers have both increased in the past ten years. The former now breed nearby with pairs at the University of Glasgow and the Anniesland gasometers, with birds regularly flying over GBG revealed by their deep croaking calls. Jackdaws have bred in the city for much longer, but have recently become more common and widespread, and so are often heard and seen.

Waxwings visit Glasgow most winters in small numbers, with the last flock in GBG of up to 110 birds, from 23rd to 28th November 2016.

Passerines

A number of passerine species have been observed more over the past ten years: the sand martin, dipper, house sparrow, goldfinch and bullfinch.

Sand martins are increasingly seen in GBG, usually flying up and down the River Kelvin. This reflects both a recovery in the species' fortunes in Scotland (Forrester *et al*., 2007), and that they breed locally along the river. Interestingly, downstream in Partick, the nest sites are not the usual sand banks but instead holes in concrete walls overlooking the river; multiple pairs can use the same entrance hole.

During the 1990s the dipper was only occasionally observed along the River Kelvin during the winter but, more recently, breeding pairs can be found along the entire course of the river that passes through the West End of Glasgow; their distinctive "kkkrrrrrrr" call is a familiar sound. This increase is possibly linked to improvements in water quality; grey wagtails and kingfishers both also nest along the river.

House sparrow numbers have started to recover in the past five years from a historic low (Dott & Brown, 2000; Summers-Smith, 2003), with groups now again present where suitable vegetation such as thick hedges or ivy-clad walls are found. Goldfinches are common and widespread, with bullfinches frequently heard and seen.

Summer migrant warblers have also increased in numbers in recent years. More blackcaps and chiffchaffs are recorded in the Gardens, not only as breeding birds, but also on passage in spring and late summer/autumn. Willows warblers have shown the same increase in passage numbers but breed elsewhere, some nearby. Wood warblers have been observed just twice, both in April, near to GBG on passage presumably to breeding areas further north in Scotland.

New to the list, meadow pipits were recorded each autumn as passage migrants, with the skylark more infrequent: for example, two of the latter were heard and seen flying over on 1st November 2008. Both siskins and lesser redpolls were noted as regular winter visitors.

Three very rare observations during the period were of the firecrest, crossbill and hawfinch, with each seen just once in the vicinity of GBG. The male firecrest was present from 11th to 31st December 2017, the crossbills a group of two or three birds flying past on 14th April 2020 giving their "chip chip" call, and the hawfinch on 21st April 2005 (McInerny, 2007).

DISCUSSION

GBG hosts an interesting range of species of birds, some of which have shown striking fluctuations over the years. It will be fascinating to see what further changes occur in the future and which new species will be next added to the GBG bird list. My predictions include the pied flycatcher (*Ficedula hypoleuca*), sedge warbler (*Acrocephalus schoenobaenus*) and tree pipit (*Anthus trivialis*), all of which breed in Scotland as summer visitors from Africa, and likely pass through the area on migration; and the Jay (*Garrulus glandarius*), a resident breeder which is expanding its range and had been noted recently in north Glasgow.

REFERENCES

Dott, H.E.M. & Brown, A.W. (2000). A major decline in house sparrows in central Edinburgh. *Scottish Birds* 21, 61-68.

Downie, J.R. & Forster, S.J. (2019). On the wildside 2: the natural history of the Glasgow Botanic Gardens revisited. *The Glasgow Naturalist* 27(1), 49. https://doi.org/10.37208/tgn27108

Forrester, R.W., Andrews, I.J., McInerny, C.J., Murray, R.D., McGowan, R.Y., Zonfrillo, B. *et al.* (Editors). (2007). *The Birds of Scotland.* The Scottish Ornithologists' Club, Aberlady.

Forster, S.J. (2019). A "wild day out!": finding wildlife in the Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(1), 50-52. https://doi.org/10.37208/tgn27109

Grist, N.R. & McCallum, I.C. (1998). Birds for all seasons. *The Glasgow Naturalist* 23(3), 52-54.

McInerny, C.J. (2007). Hawfinch in Clyde. *Clyde Birds* 17, 120-125.

McInerny, C.J. (2016). Ring-necked parakeets potentially nesting in Scotland for the first time. *Scottish Birds* 36, 211-212.

McInerny, C.J. (2017). Ring-necked parakeets successfully breed in Scotland for the first time. *Scottish Birds* 37, 316.

McInerny, C.J. (2018). Wall-nesting urban stock doves in Glasgow. *Scottish Birds* 38, 141-142.

McInerny, C.J. (2020). Annual occupancy of an urban stock dove colony in Glasgow. *Scottish Birds* 40, 128-130.

McInerny, C.J., Musgrove A.J., Stoddart A., Harrop A.H.J., Dudley S.P. & British Ornithologists' Union Records Committee (BOURC). (2018). The British List: a Checklist of Birds of Britain (9th edition). *Ibis* 160, 190-240. https://doi.org/10.1111/ibi.12536

Paterson, J. (1927). Night-heron in Glasgow. *Scottish Naturalist* 1927, 14. https://www.biodiversitylibrary.org/item/204149#page/26/mode/1up

Summers-Smith, J.D. (2003). The decline of the house sparrow: a review. *British Birds* 96, 439-446.

The Glasgow Naturalist (2021) Volume 27, Part 3, 77-85 https://doi.org/10.37208/tgn27310

The lichens of Glasgow Botanic Gardens

I.C. Wilkie

Institute of Biodiversity, Animal Health and Comparative Medicine, University of Glasgow, Glasgow G12 8QQ

E-mail: iain.wilkie@glasgow.ac.uk

ABSTRACT

A total of 62 lichen taxa was found during a survey of Glasgow Botanic Gardens, Scotland conducted in 2018-20. This adds 54 taxa to the previous list of 14 recorded in the Gardens. Twelve lichen species have not been previously recorded in Glasgow and two - *Catillaria nigroclavata* and *Verrucaria dolosa* - are new to VC77 (Lanarkshire). Factors affecting the distribution and diversity of lichens in the Gardens are discussed.

INTRODUCTION

Lichens are fungi that form a stable symbiotic relationship with algae or cyanobacteria ("blue-green algae"). They thrive on a huge range of both natural and man-made substrates from the Arctic and Antarctic to the tropics, and from the intertidal zone to an elevation of at least 7,400 m in the Nepalese Himalayas (Lutzoni & Miadlikowska, 2009; Baniya *et al.*, 2010). Whilst the vast majority of lichens are highly sensitive to air pollution of one form or another, the relatively few that are more tolerant ensure that lichens are rarely absent from city centres: even in the 1920s, around the time when Glasgow was at its industrial zenith, it was noted that lichens were present in all municipal wards of the city (Stewart, 1925).

There is very little published literature on the lichens of Glasgow. It appears that Stewart's paper cited above is the only one devoted exclusively to this component of the city's biota. Stewart found 11 species. The only other publication providing information on Glasgow's lichens is Elliot (1901), which gives the city as the location of 12 species, none of which was subsequently recorded by Stewart (1925). Other information on Glasgow lichens is contained in "grey" literature such as commissioned environmental surveys and student theses, but these tend to be poorly catalogued and difficult to access. The most up-to-date source of information on the distribution of British lichens is the British Lichen Society (BLS) Database, which currently gives Glasgow as a location of 158 lichen species (B.J. Coppins, pers. comm.).

The earliest record of lichens in Glasgow Botanic Gardens (GBG) is that of O'Hare (1974), who found only the crustose species *Lecanora conizaeoides*, which is highly tolerant of sulphur dioxide pollution and was then the commonest lichen in the city. The present author made brief visits to GBG in 1975 and 1986, recording a total of 14 species.

This paper describes the results of a survey of the lichens of GBG conducted in 2018-20, during which an additional 54 species were found.

MATERIALS AND METHODS

The Gardens were visited on seven occasions in 2018-20, the total time spent on the survey being *ca.* 15 h. All types of potential lichen substrates were examined, i.e. the bark of trees (both *in situ* and as shed flakes); lignum (decorticated wood of park benches and the Ha'penny Bridge); stone (both dressed and undressed or natural surfaces); brick; man-made calcareous substrates (mortar and concrete); and asphalt paths.

Small samples of all crustose (crust-like) species and most foliose (leaf-like) and fruticose (bush-like) species were collected and identified in the laboratory. The identification of samples was based on standard chemical spot tests, examination of external features in a Leica Wild M32 stereomicroscope, examination of squash preparations of fungal fruiting bodies in an Olympus CX40 compound light microscope, and consultation of keys in Smith *et al.* (2009) and Dobson (2018). Squash preparations were preserved in lactophenol cotton blue. The identification of all critical material, including most crustose samples, was verified by Dr B.J. Coppins, who is the British Lichen Society Database Manager for Scotland. The nomenclature follows that of the *Lichen Taxon Dictionary* of the British Lichen Society (https://www.britishlichensociety.org.uk/resources/lichen-taxon-database).

RESULTS

General

The main features of the lichen communities present on each type of substrate are described first and then an annotated list of the lichen taxa found in GBG is provided. The results are summarised in Table 1, which also indicates those species not previously recorded in NS56 (the 10 km square within which GBG is located), Glasgow or VC77 (Lanarkshire), according to the BLS Database (B.J. Coppins, pers. comm.). Information on previous records was obtained from the same database.

Taxon name	Substrate																	Abundance in GBG	New to NS56	New to Glasgow	New to VC77
	Alder	Ash	Beech	Birch	Bristol whitebeam	Hawthorn	Horse chestnut	London plane	Norway maple	Oregon maple	Pine	Rowan	Lignum	Stone	Concrete/mortar	Brick	Asphalt				
Anisomeridium polypori										X								R			
Arthonia radiata	X	X							X			X						F			
Baeomyces rufus														X				R			
Caloplaca chlorina														X				R	X	X	
Caloplaca citrina s. lat.														X	X			O			
Candelariella vitellina f. *vitellina*														X				R			
Candelariella xanthostigmoides		X	X	X				X	X		X		X					F			
Catillaria nigroclavata		X																R	X	X	X
Cladonia chlorophaea s. lat.	X												X					R			
Cladonia coniocraea		X							X					X				O			
Cladonia macilenta									X									R			
Clauzadea monticola															X			R			
Evernia prunastri	X										X							O			
Flavoparmelia caperata	X																	O			
Fuscidea lightfootii	X							X										O			
Graphis elegans	X																	R	X		
Hypogymnia physodes	X							X			X							F			
Hypogymnia tubulosa	X																	O			
Lecania cyrtella												X						R	X	X	
Lecanora campestris subsp. *campestris*														X				O			
Lecanora carpinea	X																	R			
Lecanora chlarotera		X							X				X					C			
Lecanora conizaeoides f. *conizaeoides*											X							R			
Lecanora expallens		X		X	X						X							F			
Lecanora muralis														X			X	O			
Lecanora pulicaris													X					R			
Lecidella elaeochroma f. *elaeochroma*	X	X			X				X			X	X					C			
Lecidella scabra														X				R			
Lecidella stigmatea														X				F			
Lepraria finkii										X				X		X		F			
Lepraria incana s. str.		X	X	X	X	X	X	X			X			X				C			
Lepraria rigidula									X									R	X	X	
Leptogium gelatinosum														X				R	X	X	
Melanelixia glabratula	X			X	X				X		X							C			
Melanelixia subaurifera											X							R			
Opegrapha ochrocheila										X								R	X	X	
Parmelia saxatilis s. lat.	X																	R			
Parmelia sulcata s. lat.	X	X		X	X			X	X		X		X					C			
Parmotrema perlatum	X												X					R			
Pertusaria leioplaca									X									R			
Phaeophyscia orbicularis														X				R			
Phlyctis argena		X																R	X	X	
Physcia caesia														X				R			
Physcia tenella								X	X		X							O			
Platismatia glauca	X																	R			
Porpidia crustulata														X				R			
Porpidia soredizodes														X				R			
Protoblastenia rupestris															X			R			
Pyrrhospora quernea									X									R	X	X	
Ramalina farinacea	X																	R			
Ramalina fastigiata									X									O	X	X	
Rhizocarpon reductum														X				R			
Scoliciosporum umbrinum														X				R	X		
Trapelia coarctata														X				O			
Trapelia placodioides														X				O			
Usnea subfloridana	X								X									O			
Verrucaria dolosa														X				R	X	X	X
Verrucaria elaeina																		R	X	X	
Verrucaria muralis														X		X		R			
Verrucaria praetermissa														X				O	X	X	
Verrucaria viridula														X				R			
Xanthoria polycarpa									X									O			

Substrates

Bark

Bark is the substrate that supports the greatest lichen diversity in GBG, with 37 taxa (60% of the total number recorded in GBG) being found. There is a marked distinction between the lichen assemblages on young and mature trees.

Those on most mature trees are sparse, show low species diversity per tree (up to five species per tree), and are dominated by crustose species. The commonest lichen, and the only one present on some trees, is the bluish grey, sterile *Lepraria incana* s. str. (Fig. 1A), which is the main representative of the pollution-resistant lichen association (community sub-type) *Leprarietum incanae* (James *et al.*, 1977). Some mature trees, including London planes (*Platanus* × *acerifolia*) between the Main Lawn and Great Western Road, have impoverished traces of the *Pseudevernietum furfuraceae* association (James *et al.*, 1977) represented by the foliose species *Parmelia sulcata* s. lat., which is generally badly damaged (possibly by gastropod molluscs), and very small *Hypogymnia physodes*. As the oldest tree in GBG, the weeping ash (*Fraxinus excelsior* Pendula), planted in the original Glasgow Botanic Garden at Sandyford in 1818 and moved to its current site in 1841 (Curtis, 2006), is of particular interest. However, its trunk, heavily shaded in summer, has a very sparse scattering of lichens, which can be assigned to the *Lecanoretum subfuscae* association (see below) and is limited to a few colonies of the crustose *Lecanora chlarotera*, *L. expallens* and *Lepraria incana* (Fig. 1B). Other mature trees of note are the two large Oregon maples (*Acer macrophyllum*) at the east edge of the Arboretum, which carry an interesting assemblage consisting of two species not previously recorded in Glasgow - *Lepraria rigidula* and *Opegrapha ochrocheila* - and *Anisomeridium polypori*, previously found in Glasgow only in Linn and Pollok Parks.

By way of contrast, young trees tend to support well-developed examples of two associations - the *Lecanoretum subfuscae* and *Pseudevernietum furfuraceae*. The former is regarded as a pioneer community of young trees (James *et al.*, 1977) and comprises crustose species, particularly *Lecanora chlarotera*, *Lecidella elaeochroma* f. *elaeochroma* and *Arthonia radiata*, which on some trunks form a continuous mosaic (Fig. 1C,D). With time this community grades into the *Pseudevernietum furfuraceae*, which is dominated by foliose and fruticose species and is particularly luxuriant on the trunks of some alders (*Alnus glutinosa*) in the Arboretum (Fig. 1E,F), with *Hypogymnia physodes*, *H. tubulosa*, *Parmelia sulcata* s. lat. and *Melanelixia glabratula* being prominent components. This community can show a relatively high diversity in GBG (up to 15 species per tree) and on one alder included the pollution-sensitive species *Flavoparmelia caperata* and *Parmotrema perlatum*.

Lignum

Seven species (11% of total) were recorded on decorticated wood. Some weathered wooden benches have been colonised by *L. chlarotera* and *L. elaeochroma* f. *elaeochroma*, components of the *Lecanoretum subfuscae* association (Fig. 1G,H). Small specimens of *Cladonia chlorophaea* s. lat., *P. sulcata* s. lat. and *P. perlatum* are also present. The Ha'penny Bridge is the only location where *Lecanora pulicaris* was found.

Stone

There is a range of different stone substrates in GBG on which were found 24 species (39% of total). Lichens on dressed stone, such as that used for the low boundary walls (Fig. 1I) and the Curator's House, and the red sandstone piers of Kirklee Bridge (Fig. 1J), show a lower diversity (nine species) than those on the various types of undressed/natural stone (16 species). Regarding the latter, the rocks of various sizes used as edging around the pond and in the Herb Garden have been colonised by an inconspicuous but species-rich (n = 11) assemblage of mainly crustose species. A more conspicuous community, visually dominated by foliose species, is present on the large alkaline dolerite boulders that have been placed at the edge of the River Kelvin near the Viewpoint in the Arboretum, apparently to protect the river bank (Fig. 1K,L). A combination of factors explains the composition of this assemblage, including the presence of moss (which provides a microhabitat for the jelly lichen *Leptogium gelatinosum*), periodic submersion of the boulders (*Verrucaria praetermissa*), and nutrient enrichment by perching birds and/or the basic nature of the substrate (*Caloplaca citrina* s. lat., *Lecanora muralis*, *Phaeophyscia orbicularis*, *Physcia caesia*).

Concrete and mortar

The combination of species growing on the Jimmy Logan memorial in the Rose Garden, i.e. *Caloplaca citrina* s. lat., *Clauzadea monticola* and *Protoblastenia rupestris*, is typical for man-made calcareous substrates in city locations. *C. citrina* s. lat. is also present on the mortar of brick and stone walls in GBG.

Brick

Although no lichens were found on old bricks, such as those in the walls of the "Long Pit" behind the Main Glasshouse, *Lepraria finkii* and *Verrucaria elaeina* occur on the bricks of a relatively new retaining wall near Garrioch Bridge.

Asphalt

Lecanora muralis grows as dispersed patches on the asphalt path in the Arboretum near the Kirklee Road entrance (Fig. 1M). It is sometimes called the "chewing gum lichen" because of its resemblance (at a distance) to that all-too-common contaminant of city pavements, and is one of several lichens that can thrive in such mechanically challenging habitats.

Table 1. Summary of the results of a survey of the lichens of Glasgow Botanic Gardens, Scotland, 2018-20. C, common; F, frequent; O, occasional; R, rare. These abundance descriptors are defined in the text.


A
B
C
E
2
3
1
D
1
2
3
F
G
I
K
L
H
J
M
1 cm

Lichen taxa recorded in 2018-2020

The statement of abundance for each taxon given below and in Table 1 is based only on how often it was found in GBG and provides no information on its wider status. Lichens described as "rare" were observed in only small quantity at one or two places in GBG; those described as "occasional" occur as larger colonies at one or two places, or as only small colonies in several places; those described as "frequent" are widespread but not anywhere in large quantity; and "common" species are widespread and present in large quantity in at least some locations (adapted from James & Powell, 2010).

Anisomeridium polypori. Rare. In bark crevices of Oregon maples in Arboretum.

Arthonia radiata. Frequent. On bark of mainly young trees.

Baeomyces rufus. Rare. On sandstone rock near pond.

Caloplaca chlorina. Rare. On boulder at edge of Kelvin near Viewpoint, Arboretum. New to Glasgow. Probably under-recorded throughout the U.K., according to Smith *et al.* (2009).

Caloplaca citrina s. lat. Occasional. Very small colonies on Jimmy Logan memorial, wall of Conservatory, and mortar. British material referred to as "*C. citrina*" is likely to consist of one of several other species. It is not certain that *C. citrina* s. str. occurs in the U.K. (Powell & Vondrák, 2012).

Candelariella vitellina f. *vitellina*. Rare. On dressed stone of Queen Margaret Drive boundary wall.

Candelariella xanthostigmoides. Frequent. Very small colonies on bark of mature and younger trees, and on lignum of wooden bench. U.K. records of this species have been previously misidentified as *C. reflexa*, which has yet to be reported correctly from Britain (Coppins *et al.*, 2019; B.J. Coppins, pers. comm.).

Catillaria nigroclavata. Rare. On bark of small ash in Arboretum near Kirklee Road gate. New to VC77. However, probably common throughout the U.K. and spreading, but mistaken for other common species such as *Amandinea punctata* (Dobson, 2018).

Cladonia chlorophaea s. lat. Rare. At base of alder trunk in Arboretum and on wooded bench. *C. chlorophaea* s. lat. includes chemotypes that are sometimes given species status (Smith *et al.*, 2009).

Cladonia coniocraea. Occasional. On bark, sometimes with moss, and amongst moss on rock in Herb Garden.

Cladonia macilenta. Rare. On bark of Norway maple (*Acer platanoides*) near Kirklee Gate.

Clauzadea monticola. Rare. On concrete of Jimmy Logan memorial.

Evernia prunastri. Occasional. On bark of alders in Arboretum.

Flavoparmelia caperata. Occasional. On bark of alders in Arboretum.

Fuscidea lightfootii. Occasional. On bark of London plane near Great Western Road and alders in Arboretum.

Graphis elegans. Rare. On bark of alder in Arboretum.

Hypogymnia physodes. Frequent. On bark of London plane near Great Western Road and alders in Arboretum.

Hypogymnia tubulosa. Occasional. On bark of alder in Arboretum.

Lecania cyrtella. Rare. On bark of young rowan (*Sorbus aucuparia*) in Herb Garden. New to Glasgow.

Lecanora campestris subsp. *campestris*. Occasional. On sandstone rock near pond and sandstone wall of Curator's House.

Lecanora carpinea. Rare. On bark of alder in Arboretum.

Lecanora chlarotera. Common. On bark of young and mature trees including weeping ash transplanted from Sandyford Botanic Garden; also on lignum of wooden benches.

Lecanora conizaeoides f. *conizaeoides*. Rare. On bark of pine (*Pinus* sp.) in Arboretum.

Lecanora expallens. Frequent. On bark of mature trees including weeping ash transplanted from Sandyford Botanic Garden, and on younger trees, e.g. black pine (*Pinus nigra*) and birch (*Betula utilis*) in Arboretum; some extensive patches on London planes beside Main Lawn.

Lecanora muralis. Occasional. On sandstone rock near pond, boulders at edge of Kelvin at Viewpoint, and asphalt path in Arboretum.

Lecanora pulicaris. Rare. On lignum of Ha'penny Bridge. As this species is closely similar to *L. chlarotera* in external appearance, it may be present elsewhere in GBG and have been overlooked.

Lecidella elaeochroma f. *elaeochroma*. Common. On bark of young and mature trees, and on lignum of wooden benches.

Lecidella scabra. Rare. On dressed stone wall at Viewpoint, Arboretum.

Lecidella stigmatea. Frequent. On dressed stone walls and on rock near pond.

Fig. 1. Lichens of Glasgow Botanic Gardens, Scotland. (A) *Lepraria incana* (arrow) on lower trunk of grey poplar (*Populus* × *canescens*). 17th July 2018. (B) Trunk of weeping ash (*Fraxinus excelsior* Pendula) from original Glasgow Botanic Garden at Sandyford. The arrow indicates a colony of *Lecanora expallens*. 26th November 2019. (C) Trunk of young Norway maple (*Acer platanoides*) with well-developed example of the *Lecanoretum subfuscae* association consisting mainly of crustose lichens. 17th July 2018. (D) Some components of the *Lecanoretum subfuscae* association on trunk of young ash (*F. excelsior*), Arboretum. 1, *Lecanora chlarotera*; 2, *Lecidella elaeochroma* f. *elaeochroma*; 3, *Arthonia radiata*. 20th October 2019. (E) Trunk of alder (*Alnus glutinosa*) in Arboretum with well-developed example of the *Pseudevernietum furfuraceae* association consisting mainly of foliose and fruticose lichens. 31st July 2018. (F) Some components of the *Pseudevernietum furfuraceae* association on trunk of alder, Arboretum. 1, *Evernia prunastri*; 2, *Platismatia glauca*; 3, *Parmelia sulcata* s. lat. 20th October 2019. (G,H) Park bench near Kirklee Gate. This has been colonised by crustose lichens dominated by *L. chlarotera* (arrow). 30th July 2019. (I) Boundary wall next to Queen Margaret Drive. The prominent whitish lichen is *Trapelia coarctata*. 17th July 2018. (J) Pier of Kirklee Bridge, Arboretum. *Trapelia placodioides* is growing on a horizontal ledge (upper arrow) and *Lepraria finkii* on vertical surfaces (lower arrow). 8th July 2020. (K) Boulder in River Kelvin at Viewpoint, Arboretum. The arrow indicates *Lecanora muralis*. *Leptogium gelatinosum* grows amongst the moss on the lower part of the boulder. 30th July 2019. (L) Another boulder in River Kelvin at Viewpoint, Arboretum, with colonies of *Verrucaria praetermissa* (arrow). 8th July 2020. (M) *Lecanora muralis* on asphalt path, Arboretum. 8th July 2020. (Photos: I.C. Wilkie)

Lepraria finkii. Frequent. On bark of Oregon maple in Arboretum, dressed sandstone (Kirklee Bridge pier and wall near Kirklee Gate), mossy rock in Herb Garden, and brick wall beside pathway north of Garrioch Bridge.
Lepraria incana s. str. Common. On shaded tree trunks; some extensive patches but restricted to cracks in bark of some trees (e.g. birches in Arboretum); shaded crevices in sandstone outcrop in Arboretum.
Lepraria rigidula. Rare. On bark of Norway maple in Arboretum. New to Glasgow.
Leptogium gelatinosum. Rare. Amongst moss on boulder at edge of Kelvin near Viewpoint, Arboretum. New to Glasgow.
Melanelixia glabratula. Common. On bark of mainly young trees; notably abundant on a Bristol whitebeam (*Sorbus bristoliensis*) in Arboretum.
Melanelixia subaurifera. Rare. On bark of black pine in Arboretum.
Opegrapha ochrocheila. Rare. On bark of Oregon maple in Arboretum. New to Glasgow.
Parmelia saxatilis s. lat. Rare. On bark of alder in Arboretum. This is one of a group of dye-yielding *Parmelia* spp. known as "crotal" in Gaelic. *P. saxatilis* s. lat. comprises a complex of cryptic species that can be reliably distinguished by only molecular methods (Corsie *et al.*, 2019).
Parmelia sulcata s. lat. Common. On bark of mainly young but also (in smaller quantity) some mature trees. This is another of the "crotal" lichens. Like *P. saxatilis*, *P. sulcata* s. lat. consists of cryptic species that cannot be distinguished in the absence of molecular information (Molina *et al.*, 2011).
Parmotrema perlatum. Rare. On bark of alder in Arboretum and wooden bench.
Pertusaria leioplaca. Rare. On bark of young Norway maple behind Kibble Palace. The BLS Database has no Glasgow records of *P. leioplaca*. However, the author found it on the trunk of a sweet chestnut (*Castanea sativa*) in Pollok Park in 2012.
Phaeophyscia orbicularis. Rare. On boulders at edge of Kelvin near Viewpoint.
Phlyctis argena. Rare. On mossy trunk of ash in Arboretum. New to Glasgow.
Physcia caesia. Rare. On boulders at edge of Kelvin near Viewpoint.
Physcia tenella. Occasional. On bark of London plane near Great Western Road, young Norway maple behind Kibble Palace, and black pine in Arboretum.
Platismatia glauca. Rare. On bark of alder in Arboretum.
Porpidia crustulata. Rare. On rock in Herb Garden.
Porpidia soredizodes. Rare. On dressed stone of Queen Margaret Drive boundary wall. Although the BLS Database has no NS56 records of *P. soredizodes*, the author found it on dressed sandstone in Port Dundas in 1988.
Protoblastenia rupestris. Rare. On concrete of Jimmy Logan memorial.
Pyrrhospora quernea. Rare. On bark of Norway maple near Kirklee Gate. New to Glasgow.
Ramalina farinacea. Rare. On bark of alder in Arboretum.
Ramalina fastigiata. Occasional. On bark of young Norway maples beside Kelvin Walkway and behind Kibble Palace. Very sensitive to air pollution (Smith *et al.*, 2009). New to Glasgow.
Rhizocarpon reductum. Rare. On sandstone rock near pond.
Scoliciosporum umbrinum. Rare. On sandstone rock near pond.
Trapelia coarctata. Occasional. On dressed stone of Queen Margaret Drive boundary wall and undressed sandstone rock near pond and in Herb Garden.
Trapelia placodioides. Occasional. On dressed red sandstone of Kirklee Bridge pier. All colonies unusual in lacking soralia (discrete areas of the upper surface that produce vegetative propagules consisting of clusters of algal cells and fungal hyphae).
Usnea subfloridana. Occasional. On bark of young Norway maple beside Kelvin Walkway and alder in Arboretum.
Verrucaria dolosa. Rare. On boulder at edge of Kelvin near Viewpoint. New to VC77.
Verrucaria elaeina. Rare. On brick, wall beside pathway north of Garrioch Bridge. New to Glasgow.
Verrucaria muralis. Rare. On sandstone rock in Herb Garden.
Verrucaria praetermissa. Occasional. On boulder at edge of Kelvin near Viewpoint. New to Glasgow.
Verrucaria viridula. Rare. On dressed stone of Queen Margaret Drive boundary wall.
Xanthoria polycarpa. Occasional. On bark of young Norway maples beside Kelvin Walkway and behind Kibble Palace.

DISCUSSION

Previous records

Previous records of lichens in GBG are summarised in Table 2. Six previously recorded species were not found in 2018-20. Of these, *Candelariella aurella* and *Myriolecis dispersa* were present in 1986 on a low boundary wall at the Queen Margaret Drive entrance. These species are common in Glasgow and are likely to still occur in GBG but to have been overlooked in 2018-20. The other four species - *Cladonia digitata*, *C. fimbriata*, *Lecanora intricata* and *L. polytropa* - were found in 1986 on the low wall of the old Herb garden, which was located at that time near the Kibble Palace (Hancock, 1998; Curtis, 2006), and on rocks edging the old pond. These lichens were casualties of the subsequent removal of the Herb Garden to another site and the destruction and re-establishment of the pond during the renovation of the Kibble Palace around 2004 (Sutcliffe, 2019). All four species are common in Glasgow and may persist elsewhere in GBG.

No conclusions can be drawn from the apparently impressive addition of 54 lichen taxa to the previous GBG list of 14 species, due to the brevity of the author's visits in 1975 and 1986 and the fact that the Arboretum, which accounts for much of the present lichen diversity of GBG (see below), was not opened to the public in its present form until 1977 and was not visited by the author in 1986. There has, however, been one definite change

Taxon name	Substrate		Recorder and year
	Bark	Stone	
Candelariella aurella		X	3
Cladonia coniocraea		X	3
Cladonia digitata		X	2,3
Cladonia fimbriata		X	3
Hypogymnia physodes	X		2,3
Lecanora conizaeoides	X		1,2,3
Lecanora intricata		X	3
Lecanora polytropa		X	3
Lecidella stigmatea		X	3
Lepraria incana s. lat.	X		3
Myriolecis dispersa		X	3
Parmelia saxatilis s. lat.	X		3
Platismatia glauca	X		3
Porpidia crustulata		X	3

Table 2. Previous records of lichens from Glasgow Botanic Gardens, Scotland. Species not found in 2018-20 are highlighted in bold text. *Lepraria incana* is designated "sensu lato" because records of this species made before 1992 are unreliable due to subsequent taxonomic advances (Smith *et al.*, 2009). 1, G.P. O'Hare (1974); 2, I.C. Wilkie (1975, pers. obs.); 3, I.C. Wilkie (1986, pers. obs.).

in the lichens of GBG. The author recorded that the corticolous (growing on bark) crust *Lecanora conizaeoides* was "very common" in 1975 and "abundant" in 1986. In 2018-20 *L. conizaeoides* was "rare", occurring as small, easily overlooked, sterile colonies on the bark of a pine in the Arboretum. *L. conizaeoides* has declined dramatically across the U.K. over the past 20-30 years. It requires very acidic substrates, which were plentiful from the 19th to the late 20th centuries as a result of high levels of atmospheric sulphur dioxide caused by the burning of coal. Massara *et al.* (2009) concluded that its retreat was linked to an increase in bark pH due to a combination of the reduction in sulphur dioxide emissions that followed the Clean Air Act of 1956 and rising emissions of ammonia originating from the catalytic convertors of road vehicles. Although once very common throughout the city, *L. conizaeoides* had not been recorded in Glasgow since 1991 (pers. obs.). It may have survived on a pine trunk in GBG because of the naturally low pH of pine bark (Marmor & Randlane, 2007; Fojcik *et al.*, 2017).

Whilst a quantitative approach was not taken in either the 2018-20 survey or the brief 1975 and 1986 surveys, it is the author's subjective impression that there has been little recovery of the corticolous lichen communities on mature trees over the past 30 years. As in 1975 and 1986, non-crustose species - particularly *Hypogymnia physodes*, *Parmelia sulcata* s. lat. and *Physcia tenella* - are still sparse and present as very small or damaged individuals. In addition, other moderately pollution-tolerant non-crustose species that might have been expected to have gained a foothold, such as *Evernia prunastri* and *Platismatia glauca*, were not found on mature trees. This may be a consequence of present atmospheric levels of nitrogen compounds (discussed below) or of the "toxic legacy" of decades of air pollution that rendered old bark resistant to lichen colonisation (Powell *et al.*, 2017). In view of the presence on young trees of *E. prunastri*, *P. glauca* and other non-crustose species, the latter is more likely.

2018-20 records

In the 2018-20 survey 62 lichen taxa were found in GBG, bringing the total number recorded since 1974 to 68. The Glasgow parks whose lichens have been most thoroughly investigated are Linn and Pollok Parks, both located at the southern edge of the city and both visited independently by at least two professional lichenologists during the past 50 years. The BLS Database lists 47 lichen taxa for Linn Park and 80 for Pollok Park, suggesting that GBG has a surprisingly rich lichen diversity for a relatively small park in a quite central, urbanised location, though up-to-date information from other Glasgow parks would be needed to confirm this.

Most of the lichen species found in GBG (60% of the total number) grow on bark, there being a notable difference between the generally sparse, species-poor, mainly crustose communities associated with mature trees and the sometimes luxuriant and more diverse assemblages present on young trees. The richer lichen cover on young trees partly explains the disproportionate contribution of the Arboretum to lichen diversity in GBG. Although the Arboretum occupies only around 20% of the total area of GBG, 23 (37%) of the GBG lichen taxa were found only in it. Furthermore, of the 15 corticolous species present only on young trees, ten of these (67%) were restricted to the Arboretum. This is a reflection of both the preponderance of young trees in the Arboretum, which was not developed in its present form until the 1970s (Curtis, 2006), and the wide variety of trees that have been planted. The alders of the Arboretum make a particularly significant contribution to lichen diversity in GBG: 17 species were found on their trunks, seven of which were not recorded elsewhere in the Gardens (Table 1).

The same distinction between the lichens on mature and young trees is seen in other Glasgow parks (pers. obs.). One possible explanation is that the lichen communities currently present on young trees colonised their bark when they were at the nursery stage in a less polluted, possibly rural location and were imported into GBG with the trees. This, however, does not apply to the relatively luxuriant *Pseudevernietum furfuraceae* association on some of the alders in the Arboretum, since these trees were grown on site from seed received

in 1993 (A. Sinclair, pers. comm.). The assemblage has therefore developed *in situ* and, since it includes pollution-sensitive lichens such as *Ramalina fastigiata* (previously unrecorded in Glasgow), *Parmotrema perlatum* and *Flavoparmelia caperata*, it may be an indication of improving air quality.

The main factor restricting lichen growth in cities is air pollution. As a result of the reduction in sulphur dioxide emissions over the past 50 years, nitrogen compounds are now the main pollutants affecting lichens in Europe (Munzi *et al.*, 2014). The influence of these on lichens is complicated, with different chemical forms of different pollutants having varied effects, including direct toxicity. For example, some nitrogen compounds cause nutrient enrichment of substrates, which encourages the growth of nitrophytes - lichens that tolerate or thrive on such substrates, while at the same time, by increasing the pH of substrates (mentioned above), they inhibit acidophytes - lichens that tolerate or thrive in acidic conditions (James & Powell, 2010). An important nitrogenous pollutant is nitrogen dioxide (NO_2) derived from vehicle exhaust emissions. Air quality monitoring in Queen Margaret Drive, which is adjacent to the eastern boundary of GBG, shows that the mean level of NO_2 in 2014-2018 was 31.3 µg m^{-3} (with no apparent trend over that period) (Reid, 2019). Whilst there is evidence that this concentration of NO_2 affects lichen communities, for example by increasing the proportion of nitrophytes (Gadson *et al.*, 2010), it is also known that NO_2 levels quickly drop off away from roads (*ca.* 70% within 20-30 m: Davies *et al.*, 2007). There are indications that lichen diversity and development in GBG might be influenced by nitrogen deposition: (1) the presence of the nitrophyte *Candelariella xanthostigmoides* (albeit in very small quantity) on many mature and young trees, and on lignum; (2) the rarity of *Parmelia saxatilis* s. lat., which is usually a prominent member of the *Pseudevernietum furfuraceae* association (James *et al.*, 1977) but is also sensitive to nitrogen pollution (van Herk, 1999; Will-Wolf *et al.*, 2015); and (3) the luxuriance on some young trees, and significant presence on some mature trees, of *Parmelia sulcata* s. lat., which, though not considered to be a nitrophyte, appears to be quite tolerant of nitrogen pollution (Davies *et al.*, 2007; Smith *et al.*, 2009). If nitrogenous pollutants are inhibiting lichen colonisation and growth in GBG and other Glasgow parks, then the ongoing switch from hydrocarbon-fuelled to electrical vehicles bodes well for the future of these organisms throughout the city.

The finding of lichens new to Glasgow and new to VC77 is likely to be less a consequence of GBG possessing features extraordinarily conducive to lichen diversity, and more an indication that the city's lichens have been generally under-investigated. It is hoped that the present contribution will stimulate renewed interest in this relatively neglected aspect of Glasgow's natural history.

ACKNOWLEDGEMENTS

I am very grateful to Dr B.J. Coppins for verifying identifications and providing BLS Database records, Dr N.D.L. Clark for geological information, R.K.S. Gray and A. Sinclair for information on GBG trees, K.J. Watson for alerting me to the presence of *Leptogium gelatinosum*, and a reviewer for suggesting improvements to the text.

REFERENCES

Baniya, C.B., Solhøy, T., Gauslaa, Y. & Palmer, M.W. (2010). The elevation gradient of lichen species richness in Nepal. *The Lichenologist* 42, 83-96. https://doi.org/10.1017/S0024282909008627

Coppins, B.J., Seaward, M.R.D. & Simkin, J. (2019). British Isles list of lichens and lichenicolous fungi. September 2019 update to list. *British Lichen Society Bulletin* 125, 66-72.

Corsie, E.I., Harrold, P. & Yahr, R. (2019). No combination of morphological, ecological or chemical characters can reliably diagnose species in the *Parmelia saxatilis* aggregate in Scotland. *The Lichenologist* 51, 107-121. https://doi.org/10.1017/S0024282919000069

Curtis, E.W. (2006). *The Story of Glasgow's Botanic Gardens*. Argyll Publishing, Glendaruel.

Davies, L., Bates, J.W., Bell, J.N.B., James, P.W. & Purvis, O.W. (2007). Diversity and sensitivity of epiphytes to oxides of nitrogen in London. *Environmental Pollution* 146, 299-310. https://doi.org/10.1016/j.envpol.2006.03.023

Dobson, F.S. (2018). *Lichens. An Illustrated Guide to the British and Irish Species.* (7th edition). The Richmond Publishing Company, Slough.

Elliot, G.F.S. (1901). Lichens. In: Elliot, G.F.S., Laurie, M. & Murdoch, J.B. (Editors). *Fauna, Flora and Geology of the Clyde Area*, pp. 50-60. British Association for the Advancement of Science, Glasgow.

Fojcik, B., Chruścińska, M. & Nadgórska-Socha, A. (2017). Epiphytic habitats in an urban environment; contamination by heavy metals and sulphur in the barks of different tree species. *Polish Journal of Natural Sciences* 32, 283-295.

Gadson, S.R., Dagley, J.R., Wolseley, P.A. & Power, S.A. (2010). Relationships between lichen community composition and concentrations of NO_2 and NH_3. *Environmental Pollution* 158, 2553-2560. https://doi.org/10.1016/j.envpol.2010.05.019

Hancock, E.G. (1998). Introduction. On the wildside: the natural history of the Glasgow Botanic Gardens. *The Glasgow Naturalist* 23(3), 42-43.

James, P.W., Hawksworth, D.L. & Rose, F. (1977). Lichen communities in the British Isles: a preliminary conspectus. In: Seaward, M.R.D. (Editor). *Lichen Ecology*, pp. 295-413. Academic Press, London.

James, P.W. & Powell, M. (2010). The lichens of Sutton Park, Warwickshire. *British Lichen Society Bulletin* 107, 2-17.

Lutzoni, F. & Miadlikowska, J. (2009). Lichens. *Current Biology* 19, R502-R503. https://doi.org/10.1016/j.cub.2009.04.034

Marmor, L. & Randlane, T. (2007). Effects of road traffic on bark pH and epiphytic lichens in Tallinn. *Folia Cryptogamica Estonica* 43, 23–37.

Massara, A.C., Bates, J.W. & Bell, J.N.B. (2009). Exploring causes of the decline of the lichen *Lecanora conizaeoides* in Britain: effects of experimental N and S applications. *The Lichenologist* 41, 673-681. https://doi.org/10.1017/S0024282909990119

Molina, M.C., Divakar, P.K., Millanes, A.M., Sánchez, E., Del-Prado, R., Hawksworth, D.L. & Crespo, A. (2011). *Parmelia sulcata* (Ascomycota: Parmeliaceae), a sympatric monophyletic species complex. *The Lichenologist* 43, 585-601. https://doi.org/10.1017/S0024282911000521

Munzi, S., Correia, O., Silva, P., Lopes, N., Freitas, C., Branquinho, C. & Pinho, P. (2014). Lichens as ecological indicators in urban areas: beyond the effects of pollutants. *Journal of Applied Ecology* 51, 1750-1757. https://doi.org/10.1111/1365-2664.12304

O'Hare, G.P. (1974). *Air Pollution and Lichens in the Western Central Lowlands of Scotland.* Ph.D. thesis, University of Glasgow.

Powell, M., Beale, J. & Shipway, P. (2017). Lichens in Greenwich Park. *British Lichen Society Bulletin* 121, 45-52.

Powell, M. & Vondrák, J. (2012). Yellow sorediate crusts called "*Caloplaca citrina*" in England. *British Lichen Society Bulletin* 110, 20-24.

Reid, K. (2019). *2019 Air Quality Annual Progress Report (APR) for Glasgow City Council*. Glasgow City Council.

Smith, C.W., Aptroot, A., Coppins, B.J., Fletcher, A., Gilbert, O.L., James, P.W. & Wolseley, P.A. (2009). *The Lichens of Great Britain and Ireland.* (2nd edition). The British Lichen Society, London.

Stewart, E.J.A. (1925). Some Glasgow lichens. *Annals of the Andersonian Naturalists' Society* 4, 76-83.

Sutcliffe, R. (2019). Non-avian vertebrates in Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(1), 69-70. https://doi.org/10.37208/tgn27113

van Herk, C.M. (1999). Mapping of ammonia pollution with epiphytic lichens in the Netherlands. *The Lichenologist* 31, 9-20. https://doi.org/10.1006/lich.1998.0138

Will-Wolf, S., Jovan, S., Neitlich, P., Peck, J.E. & Rosentreter, R. (2015). Lichen-based indices to quantify responses to climate and air pollution across northeastern U.S.A. *The Bryologist* 118, 59-82. https://doi.org/10.1639/0007-2745-118.1.059

The Glasgow Naturalist (2021) Volume 27, Part 3, 86-91 https://doi.org/10.37208/tgn27321

Further insect and other invertebrate records from Glasgow Botanic Gardens, Scotland

R.B. Weddle

89 Novar Drive, Glasgow G12 9SS

E-mail: richard@canto.plus.com

ABSTRACT

This paper is one of a series providing an account of the current status of the animals, plants and other organisms in Glasgow Botanic Gardens, Scotland. It lists mainly invertebrates that have been found in the Gardens over the past 20 years in addition to those reported in other articles in the series. The vast majority of these additions are insects, though some records of horsehair worms (Nematomorpha), earthworms (Annelida: Lumbricidae), millipedes (Diplopoda) and centipedes (Chilopoda) are included.

INTRODUCTION

This paper highlights some of the invertebrates that have been found in Glasgow Botanic Gardens (GBG), Scotland, principally in the 20 years since the previous invertebrate list was published (Hancock, 1999; hereinafter referred to as the "1999 list") and most of which are also not covered in other notes in the *Wildside Revisited* series (McInerny, 2021; Weddle, 2019a,b, 2021a-d).

Many of the invertebrates mentioned are non-lepidopteran species found in the moth trap. These are marked with an asterisk and were recorded by the author in the period from 2009. Some of these species were also in the 1999 list, but are included here to provide a complete record of species present in the moth trap. Also included are species in the "by-catch" from surveys of arachnids in the Gardens and glasshouses conducted by C. Cathrine in 2017-19.

This account does not list all the species that have been recorded in the last 22 years. The full list of species found in the Gardens, including the Kelvin Walkway and wooded slopes to the north can be found at www.gnhs.org.uk/biodiversity/GBG_splist.pdf, which shows the years when first and last recorded, and is updated regularly.

INSECTS

Ephemeroptera (mayflies)

Baetidae: **Baetis* sp.

Caenidae: **Caenis luctuosa* (angler's curse); **C. robusta.*

Ephemerellidae: **Serratella ignita* (blue-winged olive), found occasionally.

Heptageniidae: **Heptagenia sulphurea* (yellow may dun), common (in moth trap). **Rhithrogena semicolorata* was added in 2020.

Leptophlebiidae: **Habrophlebia fusca* (ditch dun). **Serratella ignita* (blue-winged olive), found occasionally in the moth trap. *Ecdyonurus* sp.

Odonata (dragonflies and damselflies)

Coenagrionidae: *Coenagrion puella* (azure damselfly), one record by the old pond outside the Kibble Palace in 2011. *Pyrrhosoma nymphula* (large red damselfly), found by the new pond outside the Kibble Palace by Glasgow Countryside Rangers in 2017 during a Royal Society for the Protection of Birds (RSPB) Bioblitz.

Dermaptera (earwigs)

Anisolabididae: *Euborellia annulipes* (ring-legged earwig), a non-native recorded in the Euing Range found by E.G. Hancock in 2009, the first record for Glasgow.

Forficulidae: **Forficula auricularia* (common earwig), first record 2011 at the disused Kirklee Station, also found subsequently in the moth trap.

Psocoptera (bark-flies)

Trichopsocidae: *Trichopsocus dalii*, recorded in 1909 (King, 1910), though not included in the 1999 list.

Elipsocidae: **Elipsocus abdominalis*, in the moth trap (2016), only known record for Glasgow.

Mesopsocidae: *Mesopsocus immunis*, swept from *Eucryphia* sp. (Cunoniaceae) foliage (2019), only known record for Glasgow.

Hemiptera (true bugs)

Heteroptera

Acanthosomatidae: **Acanthosoma haemorrhoidale* (hawthorn shieldbug), two moth trap records. **Pentatoma rufipes* (red-legged shieldbug), three records, in the moth trap on one occasion (2019). **Elasmostethus interstinctus* (birch shieldbug), two found in the moth trap on two occasions, but not yet found elsewhere in GBG.

Anthocoridae: *Anthocoris nemorum* (common flower bug).

Corixidae: **Corixa panzeri*, in the moth trap on one occasion (2019); some other corixids have been seen but not yet identified in the new pond by Kibble Palace in 2017, and in the moth trap, 2020.

Miridae: *Campyloneura virgula*, a predatory bug generally found in trees, only six records for Glasgow, one in GBG, but bugs of this family are often overlooked. *Phytocoris tiliae*, an old record (Murphy, 1901), which was not included in the 1999 list. Eight other species of Miridae have been found in grassland in recent years.

Homoptera

Cicadellidae: **Empoasca vitis*, one specimen (2020), first record for Glasgow. **Edwardsiana alnicola*, one male (2020), notable-B (Kirby, 1992), first record for Scotland (Weddle, 2021b). **Fagocyba cruenta*, several males (2020). **Oncopsis flavicollis*, one specimen (2020), second record for Glasgow. **Zygina flammigera* one specimen (2020), first record for Glasgow.

Aphrophoridae: **Philaenus spumarius* (cuckoo-spit insect), one in trap (2020), common in GBG though not recorded until 2015.

Thysanoptera (thrips)

Thripidae: *Chaetanaphothrips orchidii* in the Begonia House in 2019, found by A. Sinclair.

Phasmida (stick insects)

Phasmatidae: *Carausius morosus* (laboratory stick-insect), resident in the Kibble Palace, first recorded there in 2006.

Megaloptera (alderflies etc.)

Sialidae: *Sialis* sp., probably *S. lutaria*, one recorded by S. Inglis beside the new pond outside the Kibble Palace in 2017 during a RSPB Bioblitz.

Neuroptera (lacewings)

Chrysopidae: green lacewings are seen quite frequently in the Gardens (pers. obs.) but none so far has been identified to species.

Hemerobiidae (brown lacewings): **Hemerobius atrifrons*, one record, 2016 (Weddle, 2019).

**Micromus variegatus* and **M. micans* found occasionally in the moth trap - the latter was included in the 1999 list, having been found in 1994 on a lime by E.G. Hancock.

Sisyridae (sponge-flies): **Sisyra fuscata*, first record of this family in Glasgow, one female and ten males found in 2020 among the mass of small insects that had accumulated at the bottom of the moth trap.

Trichoptera (caddisflies)

Various species occur frequently in the moth trap, sometimes outnumbering the moths. Adults of the following species were found in the moth trap in 2020 and are additional to the three species mentioned in the 1999 list.

Rhyacophilidae: **Rhyacophila dorsalis.*

Glossosomatidae: **Agapetus ochripes*. **Glossosoma boltoni.*

Hydroptilidae: *†*Agraylea multipunctata*. *†*A. sexmaculata*. *†*Allotrichia pallicornis*. *†*Hydroptila forcipata*. *†*H. sparsa.*

Polycentropodidae: **Polycentropus flavomaculatus.*

Psychomyiidae: **Psychomyia pusilla.*

Hydropsychidae: *†*Hydropsyche pellucidula*. *†*H. siltalai.*

Goeridae: **Goera pilosa*. **Silo pallipes.*

Lepidostomatidae: **Lepidostoma hirtum.*

Limnephilidae: **Anabolia nervosa*. **Halesus radiatus*. **Limnephilus auricula*. **L. flavicornis*. **L. lunatus*. **L. marmoratus*. **L. rhombicus*. **L. sparsus*. **L. vittatus*. **Potamophylax latipennis.*

Leptoceridae: **Athripsodes albifrons*. **A. bilineatus*. **Mystacides longicornis*. **Oecetis lacustris.*

Seven of these species (marked †) have not previously been recorded in Glasgow, and a further seven have not been recorded since the surveys of Binnie and King which were reported in Binnie (1876). *A. pallicornis* is nationally scarce but, as a micro-caddis that cannot be identified from the larva, it is undoubtedly under-recorded (Wallace, 2016). There are few records of *H. sparsa* from Scotland and it is "probably notable" here and in northern England (Wallace, 2016).

Coleoptera (beetles)

Species found in the course of C. Cathrine's arachnid surveys (2017-2019) are marked ⁺.

Dytiscidae (diving beetles): **Agabus* sp., one in the moth trap in 2019.

Carabidae (ground beetles): *Amara eurynota*. *A. ovata*. ⁺*A. similata*. *Bembidion lampros*. **Bradycellus harpalinus*. **B. sharpi*. *B. verbasci*. **Harpalus rufipes* (turnip mud beetle). *Nebria brevicollis*. ⁺*Pterostichus strenuus*. ⁺*Trechus obtusus*. ⁺*T. quadristriatus*.

Hydrophilidae (water scavenger beetles): **Helophorus aequalis*. **H. brevipalpis*. **Hydrobius fuscipes*. In addition, a large number of a rather small species, as yet unidentified, was found in a Heath trap in the Children's Garden in 2016.

Ptiliidae: ⁺*Acrotrichis danica*, first Glasgow record, scarce in Scotland (Cathrine, pers. comm.).

Staphylinidae (rove-beetles): **Deleaster dichrous*, designated "nationally notable B" (Hyman, 1994) on account of its rarity, though apparently not currently designated; found each year from 2015-20; the gravel-covered benches in the Long Pit and the similarly-covered raised beds beside the moth trapping site may be suitable habitats as this species normally frequents the edges of stony streams; it has also been found in moth traps in South Lanarkshire. ⁺*Medon apicalis*, "notable" (Hyman, 1994). ⁺*Metopsia clypeata*. ⁺*Stenus bimaculatus*. ⁺*S. brevipennis*. ⁺*S. brunnipes*. ⁺*S. clavicornis*. ⁺*S. impressus*. ⁺*S. ossium*. ⁺*S. picipes*. ⁺*S. similis*. ⁺*Tachinus proximus*. ⁺*Tachyporus chrysomelinus /dispar*. ⁺*Xantholinus linearis*. *X. longiventris*.

Scarabaeidae (dung beetles and chafers): **Aphodius rufipes* one record from the moth trap (2019), not recorded elsewhere in GBG, though common in moth traps generally, there are records from moth traps and pitfall traps elsewhere in Glasgow (pers. obs. and Glasgow Museums Biological Records Centre (GMBRC)). **Serica brunnea* (brown chafer).

Elateridae (wireworms): one, probably *Athous haemorrhoidalis* but unconfirmed, found by The

Conservation Volunteers (TCV) in 2017, though likely to be common in the wilder areas of the Gardens.
Cantharidae (soldier beetles): **Malthodes marginatus*, one of the smaller species in this group (2016).
Dermestidae: *Anthrenus verbasci* (carpet, or museum, beetle), on ox-eye daisy (*Leucanthemum vulgare*) in 2020.
Coccinellidae (ladybirds): **Calvia quattuordecim-guttata* (cream-spot ladybird): of 12 GBG records (1983-2019) only one was in the moth trap. **Halyzia sedecimguttata* (orange ladybird), of nine GBG records, all since 1999, five were in the moth trap, the first of which was found by G. Irving in 2002 and is therefore among the earliest sightings of this species in the Clyde area (Weddle, 2011). *Coccinella septempunctata* (7-spot ladybird), surprisingly not recorded in the Gardens until 2017 when the RSPB Wildlife Area was established.
Latridiidae: +*Cartodere nodifer.*
Oedemeridae (false blister beetles): +*Oedemera virescens*, one in the wildlife area in 2020, this species has recently become locally common in the Clyde area, though "nationally rare" in the U.K. (Philp, 2014).
Cerambycidae (longhorn beetles): one, thought to be *Clytus arietis* (wasp beetle), found during the 2015 Bioblitz by A. Malcolm, but flew away before its identity could be confirmed.
Chrysomelidae (leaf beetles): *Altica* sp. (flea beetle). *Gastrophysa viridula* (green dock beetle). *Oulema melanopus* s.l. (cereal leaf beetle).
Apionidae (weevils): +*Protapion apricans* (clover seed weevil).
Curculionidae (weevils): +*Barypeithes araneiformis* (spider weevil). +*B. pellucidus* (hairy spider weevil). **Cionus scrophulariae* (figwort weevil). +*Leiosoma deflexum*. *Orchestes fagi* (beech leaf miner). +*Otiorhynchus singularis* (clay-coloured weevil). +*Sitona lineatus* (pea-leaf weevil).

Lepidoptera (butterflies and moths)
Hancock (1999) lists no butterflies. However, of the 26 native or migrant butterfly species that have been recorded in Glasgow over the last two centuries, 12 have been recorded in the Gardens. Although there are no GBG records of butterflies prior to 1983, it must be remembered that the Glasgow city boundary has expanded markedly since the mid-19th century when sites such as Possil Marsh, Kelvingrove and Glasgow Botanic Gardens (or "Kelvinside" as the site was then known) are often recorded simply as "near Glasgow".

All butterfly species recorded in GBG are listed below. Of these, the following are recent arrivals, or re-arrivals, in south-west Scotland:
Pieridae: *Anthocharis cardamines* (orange-tip), arrived in Glasgow in 1980 after an absence from the Clyde area of over a century; was first recorded in the GBG in 1994 and is now the most frequently recorded butterfly there.
Nymphalidea: *Polygonia c-album* (comma), first recorded in the Gardens in 2016; its recent history is fully described by McInerny (2021). *Aphantopus hyperantus* (ringlet), though present in the Clyde area until the mid-20th century, there are no 19th or early 20th century records within the city; it arrived back in the Clyde area in the 1980s, but did not become established in Glasgow until the 1990s, though there was a one-off sighting in 1984 (R. Sutcliffe, pers. comm.), and it was not recorded in the Gardens until 2019.

Three of the species are migrants.
Pieridae: *Colias croceus* (clouded yellow), flies in from north Africa and southern Europe up the west coast of Scotland, but less common this far inland; the first Glasgow record was in 1938, but thereafter there were few records until 1992 when there were 40 records, one of which was in GBG. Of the relatively few sightings in subsequent years, none was in the Gardens.
Nymphalidea: *Vanessa cardui* (painted lady), a migrant from north Africa, but breeding at several points on its journey to Scotland and beyond; although there are 19th century records from the Clyde area, it was not recorded in Glasgow until 1944, and not in GBG until 2019, which was a "painted lady year" when there was a notable influx of many tens of millions of individuals countrywide. *V. atalanta* (red admiral), another migrant, but there is evidence of over-wintering in the Clyde area in recent years; in the 19th century it was described as ‘"common in the Clyde area, and abundant in some years" (Dalglish, 1901), but the first specifically Glasgow record was in 1922, and the first in GBG was in 1992.

The remaining GBG species are resident in the Glasgow area:
Nymphalidea: *Aglais io* (peacock), rare in Scotland until the mid-1990s when there was a very notable migration into Scotland, leading to new populations being established, from which the numbers have increased (R. Sutcliffe, pers. comm.); numbers may be augmented by migrants later in the year, against this background there is a surprisingly early GBG record in 1983, but it was not seen regularly there until the last five or six years. *A. urticae* (small tortoiseshell), first recorded in GBG in 1992. *Maniola jurtina* (meadow brown), though generally common in and around Glasgow, there are only two records from GBG, both in 2019.
Pieridae: *Pieris brassicae* (large white), first recorded in GBG in 2006. *P. rapae* (small white), first recorded in GBG in 2007. *P. napi* (green-veined white), not recorded in GBG until 2011, though now the commonest *Pieris* species.

An account of the moths in the Gardens is given by Weddle (2019b). However, another 26 species have been recorded in the subsequent two years (pers. obs.). Of those, the following are worthy of note:
Argyresthiidae: **Argyresthia trifasciata* non-native invasive, on juniper (*Juniperus* sp.) and Leyland cypress (*Cupressus* × *leylandii*).
Tortricidae: **Clavigesta purdeyi* (pine leaf-mining moth), first Glasgow record and second in Scotland (Weddle, 2019a).
Erebidae:**Eilema depressa* (buff footman), recent arrival in Scotland; first Glasgow record.

Noctuidae: *Leucania comma* (shoulder-striped wainscot), "Watching brief only" (Scottish Biodiversity List, 2020).

Diptera (two-winged flies)
Since the 1999 list, recording of this group has been restricted mainly to hoverflies and species that have been found in the moth trap. Some 40 of the larger insects from the trap have so far been identified to species, though there is often an accumulation of very small flies in the base of the trap; these include nematoceran species such as Chironomidae (non-biting midges), together with Psychodidae (moth flies) and Dolichopodidae (long-legged flies), as well as further species from the families mentioned below.

Tipulidae (craneflies): *Tipula staegeri*. **T. oleracea*. **T. paludosa*. *T. rufina*. **T. montium.*
Limoniidae: **Ilisia maculata*. **Rhipidia maculata.*
Trichoceridae (winter gnats): **Trichocera regelationis.*

Ceratopogonidae (biting midges): **Culicoides impunctatus.*
Stratiomyidae (soldier flies): **Beris chalybata* (murky-legged black legionnaire). **Chorisops tibialis* (dull four-spined legionnaire). **Microchrysa polita* (black-horned gem).
Empididae: **Rhamphomyia flava.*
Syrphidae (hoverflies): **Episyrphus balteatus* (marmalade hoverfly). **Melanostoma mellinum*. *Syrphus torvus*, a relatively rarely-recorded species in this area, which was netted in the RSPB wildlife area in 2017.
Agromyzidae: *Chromatomyia syngenesiae* (chrysanthemum leaf-miner), found in a glasshouse and determined from the adult by dissection by B. Warrington (2018); a common species, until recently recorded as *Phytomyza atricornis*, which is now known to be an aggregate. *Phytoliriomyza melampyga*, leaf-mines in Himalayan Balsam (*Impatiens glandulifera*) growing on the banks of the River Kelvin.
Tachinidae: **Dexiosoma caninum.*

Hymenoptera (bees, wasps etc.)
24 records have been added to the list in the last 22 years; these include the honey bee (*Apis mellifera*) and the common wasp (*Vespula vulgaris*).
Cynipidae: *Andricus quercuscalicis* (oak knopper gall, agamic), was recorded in 2020 on oak (*Quercus robur*) (pers. obs.); this wasp is listed as an invasive species and requires Turkey oak (*Quercus cerris*) for the alternate sexual generation; there is a Turkey oak in the Gardens, *ca.* 320 m away from the oak, near the Main Gate (R. Gray, pers. comm.).
Colletidae: *Colletes daviesanus* (Davies' colletes), recorded once in 2017 though probably common in the Gardens; listed in the Scottish Biodiversity List (2020) as occurring in fewer than six 10 km squares in Scotland. However, a recent increase in recording effort has significantly increased the known distribution (National Biodiversity Network (NBN), 2020), and it should be remembered that it is likely there are further records as yet unsubmitted to NBN, which would include this and other recent records in the GMBRC database.
Megachilidae: *Osmia rufa* (red mason bee), recorded on four occasions between 2011 and 2018; also listed on the Scottish Biodiversity List (2020), but as "Watching brief only".
Apidae: *Nomada panzeri* s.l. (Panzer's nomad bee), recorded once in 2012 at the disused Kirklee Station (pers. obs.); this is the only Glasgow record.

OTHER INVERTEBRATES
Few invertebrates other than those listed above and in other papers in the *Wildside* series have been recorded in the Gardens over the last 22 years. The following species from other groups, some of which are earlier records, are worthy of mention:

Nematomorpha (horsehair worms)
Gordiidae: *Gordius* sp., one found in the River Kelvin by TCV during the 2016 Bioblitz (A. Malcolm), and identified by P. Maitland from a photo. It is the only horsehair worm recorded in the GMBRC database.

Annelida (segmented worms)
Lumbricidae (earthworms): *Aporrectodea caliginosa* (grey worm), one found in the main lawn by J. Dempster during a "worm-charming" event in the 2017 Bioblitz.

Diplopoda (millipedes)
It seems that the 1999 list did not take into account unpublished records generated in 1996 by G. Corbet and therefore did not include the following species found on that visit:
Blaniulidae: *Archiboreoiulus pallidus* (spotted snake millipede). *Boreoiulus tenuis.*
Chordeumatidae: *Melogona scutellaris.*
Craspedosomatidae: *Nanogona polydesmoides* (eyed flat-backed millipede), found again in 2009 (M. Burns *et al.*).
Julidae: *Ophyiulus pilosus*. *Tachypodoiulus niger* (white-legged snake millipede).
Another species was found in 2009 by M. Burns *et al.*:
Polydesmidae: *Polydesmus angustus* (common flat-backed millipede).

Chilopoda (centipedes)
Geophilidae: *Geophilus insculptus*, recorded in 1996 by Corbet but not included in the 1999 list.

DISCUSSION
The comparative lack of records of many invertebrate groups in GBG, particularly in earlier years, may be partly because the local recorders were more focused on the biodiversity "hot-spots" in and around the City, such as Possil Marsh, and therefore tended to neglect what was at first a private estate, and then essentially a public garden. Another possible factor is that pesticides were widely used in the Gardens and glasshouses prior to the 1980s (A. Sinclair, pers. comm.), which would have discouraged recording. One significant exception is the woodlice recorded by Patience in the glasshouses and elsewhere in the Gardens in the early 20th century (Hancock, 1999), though many of them have not been

recorded there since, no doubt due to subsequent improvements in plant hygiene. The lack of butterfly records in the second half of the 20th century prior to 1983 may be due to visiting naturalists taking them for granted (E.G. Hancock, pers. comm.), as, even if pesticides prevented them breeding in the Gardens, adults could easily visit from neighbouring domestic gardens.

The establishment of the RSPB wildlife area in 2016 has had a significant effect on the invertebrates recorded in the Gardens, partly because of the perennial wildflowers planted there, but also because of the unmown grass. The area features a "bee-wall" intended to encourage nesting by solitary bees, and as a hibernaculum for these and other insects, but there is as yet no clear sign of it being used, at least by solitary bees. The adjacent Chronological Border has also yielded some interesting pollinator species, as have the various beds in the new Herb Garden and the nearby beds used for teaching horticulture.

As mentioned above, there is often an accumulation of small insects in the moth trap which can be extremely difficult to identify to species. These include nematoceran groups mentioned above under Diptera, and parasitic Hymenoptera. I have retained a number of specimens, mainly small (<5 mm) beetles, that are potentially identifiable. As discussed by Weddle (2021b), many of these small species may be merely under-recorded, in part because of their size, and in many cases because their identification requires dissection, which usually requires specialist skills.

The use of a "bug vac" – a motorised suction device - in the 2019 arachnid surveys facilitated the collection of the beetles marked "+" above, and other specimens from groups such as Hemiptera, which are yet to be identified. There can be no doubt that this and other techniques, such as pitfall traps and Malaise traps, would add considerably to the knowledge of the invertebrate population, though the practicalities of implementing most of these methods in a public green-space may well limit their coverage.

The Friends of the River Kelvin in the person of the late Allan Twigg organised the local anglers in a "Citizen Science" project to record "river-flies" – mayflies, lacewings and caddisflies - by kick-sampling the aquatic larvae. These were identified only to family, and are not included here, but the project highlights yet another technique that could potentially generate further additions to the species list. There is also scope for more recording of leaf-mines and galls. In summary, if there were enough willing recorders and identifiers, the invertebrate list could be augmented for many years to come.

ACKNOWLEDGEMENTS

Thanks are due to Ewen Donaldson, Andrew Sinclair and other GBG staff for facilitating recording visits, and to all those who have shared their records with Glasgow Museums Biological Record Centre. I am also grateful to Kirsty Godsman at Caledonian Conservation for identifying beetles found by Chris Cathrine in the course of his arachnid surveys, to Sharon Flint for identifying caddises, Craig Macadam for identifying mayflies and lacewings, Geoff Hancock for identifying several tipulids and other Diptera, Jeanne Robinson for confirming the record of *Nomada panzeri*, and Richard Sutcliffe for comments on the butterflies. Joe Ostoja-Starzewski of FERA (U.K. Food and Environment Research Agency) identified the thrips. I should also mention that the RSPB "Giving Nature a Home" team and The Conservation Volunteers organised several events which generated many records (Downie & Forster, 2019).

REFERENCES

Binnie, F.G. (1876). Trichoptera. In: Alston, E.R., Gray, R., Cameron, P., Ramsay, J. & Stirton, J. (Editors). *Notes on the Fauna and Flora of the West of Scotland*, pp. 19-21. Blackie & Son, Glasgow.

Dalglish, A.A. (1901). Macro-Lepidoptera. In: Scott Elliot, G.F., Laurie, M. & Murdoch, J.B. (Editors). *Fauna, Flora and Geology of the Clyde Area*, pp. 223-245. University of Glasgow Press, Glasgow.

Downie, R.J. & Forster, S.J. (2019). On the Wildside 2: the natural history of Glasgow Botanic Gardens revisited. *The Glasgow Naturalist* 27(1), 49. https://doi.org/10.37208/tgn27108

Hancock, E.G. (1999). Hidden wildlife: the resident population of invertebrates. *The Glasgow Naturalist* 23(4), 59-64.

Hyman, P.S. (revised Parsons, M.S.) (1994). *A Review of the Scarce and Threatened Coleoptera of Great Britain. Part 2.* UK Nature Conservation: 12. Joint Nature Conservation Committee, Peterborough.

King, J.J.F.X. (1910). List of the "Clyde" Copeognatha, or Psocidae. *The Glasgow Naturalist* 2, 34-36.

Kirby, P. (1992). *A Review of the Scarce and Threatened Hemiptera of Great Britain*. JNCC, Peterborough.

McInerny, C.J. (2021). Increased observations of comma butterflies in Glasgow Botanic Gardens and south-west Scotland. *The Glasgow Naturalist* 27(3), 95-96. https://doi.org/10.37208/tgn27310

Murphy, J.E. (1901). Hemiptera; In: Scott Elliot, G.F., Laurie, M. & Murdoch, J.B. (Editors). *Fauna, Flora and Geology of the Clyde Area*, pp. 306-309. British Association for the Advancement of Science, Glasgow.

Philp, B. (2014). *Oedemera virescens* (Linnaeus) (Oedemeridae) in Scotland. *The Coleopterist* 23(1), 17.

Wallace, I.D. (2016). *A Review of the Status of the Caddis Flies (Trichoptera) of Great Britain*. Natural England Commissioned Report NECR191.

National Biodiversity Network (2020). https://scotland-species.nbnatlas.org/species/NHMSYS0000875723 Accessed November 2020.

Scottish Biodiversity List (2020). https://www.nature.scot/scottish-biodiversity-list Accessed November 2020.

Weddle, R.B. (2011). The history and current status of the orange ladybird *Halyzia sedecimguttata*

(Linnaeus, 1758) in the Clyde area in the UK context (Coleoptera: Coccinellidae). *The Glasgow Naturalist* 25(3), 79-82.

Weddle, R.B. (2019a). The brown lacewing *Hemerobius atrifrons* (Neuroptera: Hemerobiidae) in Glasgow Botanic Gardens, Scotland. *The Glasgow Naturalist* 27(1), 68. https://doi.org/10.37208/tgn27112

Weddle, R.B. (2019b). The moths (Lepidoptera) of Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(1), 53-56. https://doi.org/10.37208/tgn27110

Weddle, R.B. (2021a). *Clavigesta purdeyi* (Lepidoptera: Tortricidae): a moth new to Scotland. *The Glasgow Naturalist* 27(3), 107. https://doi.org/10.37208/tgn27312

Weddle, R.B. (2021b). *Edwardsiana alnicola* (Hemiptera: Cicadellidae): a leaf-hopper new to Scotland, in Glasgow Botanic Gardens. *The Glasgow Naturalist* 27(3), 92. https://doi.org/10.37208/tgn27317

Weddle, R.B. (2021c). The landhopper *Arcitalitrus dorrieni* (Crustacea: Amphipoda) in Glasgow Botanic Gardens, Scotland. *The Glasgow Naturalist* 27(3), 92-93. https://doi.org/10.37208/tgn27313

Weddle, R.B. (2021d). The molluscs and crustaceans of Glasgow Botanic Gardens, Scotland. *The Glasgow Naturalist* 27(3), 93-95. https://doi.org/10.37208/tgn27317

https://doi.org/10.37208/tgn27319

Edwardsiana alnicola (Hemiptera: Cicadellidae): a leaf-hopper new to Scotland, in Glasgow Botanic Gardens

R.B. Weddle

89 Novar Drive, Glasgow G12 9SS

E-mail: richard@canto.plus.com

In another article on the fauna of Glasgow Botanic Gardens, Scotland I mention the "other insects" that are attracted to the moth trap I run, with the help of the staff at the Gardens, at the west end of the Long Pit glasshouse (Weddle, 2021). These insects are generally within the size range of the majority of the moths, i.e. *ca.* 5-90 mm in length or wing-span. However, particularly in the late summer, in the base of the trap there is typically a mass of very small, dead or moribund insects and other invertebrates, which were previously ignored. Recent examination of this material under a dissecting microscope revealed a number of interesting species, including some micro-moths that would otherwise have been overlooked. Many of these species are listed and commented on in Weddle (2021).

One of these small insects was a yellowish leafhopper, about 4 mm in length, which proved to be a species new to Scotland and not commonly recorded in the rest of the U.K. It was identified by Joe Botting as a male *Edwardsiana alnicola* (Edwards, 1924) an example of which from Austria is shown in Fig. 1.

Fig. 1. *Edwardsiana alnicola* (male); length *ca.* 4 mm. Pongau district of Salzburg, Austria. (Photo: Betty van Middelkoop)

The individual was collected at NS56796755 on 12th August 2020. The previous most northerly record of this species is to the south of Selby in Yorkshire, England as indicated on the map shown at the Auchenorrhyncha Recording Scheme (2021), which shows rather few records, sparsely distributed over England and Wales south of Yorkshire. It is not clear if this sparseness necessarily indicates rarity, as leafhopper species whose identification requires dissection and very detailed scrutiny of minute features of the aedeagus (intromittent organ) tend to have very low counts of records (A.J.A. Stewart, pers. comm.).

The Glasgow Museums Biological Records Centre database contains no records of *E. alnicola*, though it does have records of five other *Edwardsiana* species, all from the late 19th century. These do not appear on the distribution maps at the Auchenorrhyncha Recording Scheme (2021), as these records have still to be shared with the Scheme.

As its specific name implies, *E. alnicola* feeds on alder (*Alnus* spp.) leaves. There are several alders in the Gardens; one of these is a large Italian alder (*A. cordata*) behind the Euing Range of glasshouses, and within 100 m of the moth trap.

I am grateful to Joe Botting for agreeing to identify the batch of cicadellids containing this species, and to him and Alan Stewart, the organiser of the U.K. Auchenorrhyncha Recording Scheme (2021), for helpful comments.

RERERENCES

Auchenorrhyncha Recording Scheme (2021). http://www.ledra.co.uk/maps.html Accessed 4th February 2021.

Weddle, R.B. (2021). Further insects and other invertebrates in Glasgow Botanic Gardens, Scotland. *The Glasgow Naturalist* 27(3), 86-91. http://doi.org/10.37208/tgn27321

https://doi.org/10.37208/tgn27313

The landhopper *Arcitalitrus dorrieni* (Crustacea: Amphipoda) in Glasgow Botanic Gardens, Scotland

R.B. Weddle

89 Novar Drive, Glasgow G12 9SS

E-mail: richard@canto.plus.com

The landhopper *Arcitalitrus dorrieni* (Hunt, 1925) was not mentioned in Hancock's original account of the invertebrates in Glasgow Botanic Gardens (Hancock, 1999) but was first discovered there during a Bioblitz in 2017 and has been seen in each subsequent year to 2020 (pers. obs.). Indeed, the species was not found in Glasgow until 2009, when it was discovered beside the

River Kelvin in Bunhouse Road, Glasgow (Hancock, 2012).

A. dorrieni is the U.K.'s only truly terrestrial amphipod (shrimp-like crustacean) and is typically found in damp leaf-litter. In Glasgow Botanic Gardens it is found close to the stone wall boundary at the Victorian houses of Kirklee Circus, and on the edges of the woodlands sloping down to the River Kelvin opposite. Hancock's 2009 sighting was the first in the mainland part of the Clyde area, though it was previously recorded in many Hebridean islands, and it now seems to be widespread in western coastal areas, having been seen in the Isle of Bute, Dunoon and several other towns in the Clyde area, particularly in cemeteries and parks (G. Collis, pers. comm.; Collis & Collis, 2016).

The author, with The Conservation Volunteers, also found *A. dorrieni* in 2019 beside the River Kelvin in Kelvingrove Park during a Bioblitz, and Hancock also found it at Bellahouston Park, Glasgow (Hancock, 2012), so it is clearly widespread in Glasgow. (Fig. 1).

Fig. 1. A specimen of the landhopper *Arcitalitrus dorrieni*, found in Glasgow Botanic Gardens, August 2020; length 8 mm. (Photo: R.B. Weddle)

There is another similar species in the U.K. - the introduced semi-terrestrial amphipod *Cryptorchestia cavimana* (Heller, 1865), which is less darkly pigmented and, although able to penetrate far inland, rarely strays far from water margins (British Myriapod and Isopod Group, 2020). The Botanic Gardens specimens were identified as *A. dorrieni* using the key in Gregory (2016) and a specimen has been retained.

A map showing further U.K. and Ireland records of *A. dorrieni* can be seen at https://species.nbnatlas.org/species/NBNSYS0000188475 but at the time of writing this does not include any of the records mentioned in this note, nor those given in Gregory (2016), which show its presence in the north-east of England. It appears to be synanthropic (i.e. it is an undomesticated species living in close association with humans), probably spread via plant nurseries and garden centres, as there seems to be a link with ornamental gardens (Gregory, 2016). This is attested in the Clyde area by its presence in Benmore Gardens near Dunoon (Collis & Collis, 2016) and Hancock's record at Bellahouston Park was in the area of the plant nursery (Hancock, 2012).

I am grateful to Glasgow Museums Biological Records Centre for producing the full species list, and for details of some of the individual records cited; and to Glyn and Dawn Collis for additional information about the distribution in the Clyde area.

REFERENCES

British Myriapod and Isopod Group (2020). www.bmig.org.uk/species/arcitalitrus-dorrieni Accessed 15th August 2020.

Collis, G.M. & Collis, V.D. (2016). The Australian landhopper, *Arcitalitrus dorrieni* in Islay and in Cowal. *The Glasgow Naturalist* 26(2), 92-93.

Gregory, S.J. (2016). On the terrestrial landhopper *Arcitalitrus dorrieni* (Hunt, 1925) (Amphipoda: Talitridae): identification and current distribution. *Bulletin of the British Myriapod and Isopod Group* 29, 2-13.

Hancock, E.G. (1999). Hidden wildlife: the resident population of invertebrates. *The Glasgow Naturalist* 23(4), 59-64.

Hancock, E.G. (2012). The Australian landhopper, *Arcitalitrus dorrieni* (Hunt, 1925) (Crustacea: Amphipoda) in Glasgow. *The Glasgow Naturalist* 25(4), 130.

https://doi.org/10.37208/tgn27317

The molluscs and crustaceans of Glasgow Botanic Gardens, Scotland

R.B. Weddle

89 Novar Drive, Glasgow G12 9SS

E-mail: richard@canto.plus.com

This note focuses on mollusc and crustacean species that are additional to those listed as present in Glasgow Botanic Gardens by Hancock (1999).

MOLLUSCA

Since Hancock's original *On the Wildside* account (Hancock, 1999) there have been several visits to the Gardens, particularly to the glasshouses, by specialist conchologists, and several bioblitzes. This note summarises the recent findings and reviews one of the historical records mentioned by Hancock.

Nineteen species have been added to Hancock's list, mainly through recording visits by Adrian Sumner (AS) on 12th February 2013 and 6th June 2015, and by Tom Walker (TW) with Peter Dance on 4th May 2016. The former recorded both in the glasshouses and outdoors, the latter pair focused on the "hot-house aliens" which, as the name suggests, are non-native species typically introduced along with plants. Some of TW's specimens

were examined by Ben Rowson (BR) at the National Museum of Wales. Non-native species are indicated below by asterisks.

**Subulina octona* (Bruguière, 1789) has been removed from the earlier list as the specimen found by Frew in 1906, now in the Hunterian collections, Kelvin Hall, Glasgow (catalogue number GLAHM: ZB3493), is considered to be **Striosubulina striatella* auct. ?non (Rang, 1831), which is perhaps the most commonly found non-native in the glasshouses (BR, pers. comm.). An empty shell found in the Palm House by TW and initially thought to be *S. octona* because it was slenderer and had more tumid whorls than the *S. striatella* present, is now considered to be the latter species because, though somewhat worn, traces of radial striae are present and the apex is rather narrow (BR, pers. comm.). There is therefore currently no definite evidence that *S. octona* is present in the glasshouses.

Species listed in the earlier account (Hancock, 1999) are not listed again in this account even if recorded since, but one species dated earlier than 1999 which has since come to light is included.

Gastropoda (snails and slugs)
Thiaridae
**Melanoides tuberculata* (O.F. Müller, 1774). Red-rimmed melania. In a tropical pond in the Lily House (TW). There were thin and truncated *Melanoides* specimens found in the same pond and in the pond in the Orchid House (TW), but it is safe to assume that they too are *M. tuberculata* as it is a very variable species (BR)
Arionidae
Arion owenii Davies, 1979. Tawny soil slug (AS).
Arion rufus (Linnaeus, 1758). Large red slug (AS).
Arion subfuscus (Draparnaud, 1805). Dusky slug. Main Gardens and North Kelvin area (AS; J. Dempster, 2018).
Carychiinae
Carychium minimum O.F. Müller, 1774. Short-toothed herald snail. Kibble Palace (TW).
Helicidae
Cepaea hortensis (O.F. Müller, 1774). White-lipped snail. Arboretum (AS); Main Gardens (A. Malcolm, 2015).
Cepaea nemoralis (Linnaeus, 1758). Brown-lipped snail. North Kelvin area (R.B. Weddle, 2011); Main Gardens
(A. Malcolm, 2018)
The absence of both *Cepaea* species from Hancock's list is puzzling since there are records in Glasgow generally since the late 19th century (Glasgow Museums BRC).
Hygromiidae
Trochulus striolatus (C. Pfeiffer, 1828). Strawberry snail. Disused railway tunnel (E.G. Hancock, 1994).
Lauriidae
Lauria cylindracea (Da Costa, 1778). Common chrysalis snail. Kibble Palace and Orchid House (TW).
Limacidae
**Ambigolimax nyctelius* (Bourguignat, 1861). Balkan threeband slug. Kibble Palace (TW); also there and in another, unspecified, glasshouse (AS).
Lehmannia marginata (O.F. Müller, 1774). Tree slug. Kibble Palace (TW).
Limacus maculatus (Kaleniczenko, 1851). Green cellar slug. Kibble Palace (TW).
Lymnaeidae
Lymnaea stagnalis (Linnaeus, 1758). Great pond snail. In the former pond beside the Kibble Palace (M. Rutherford, 2004).
**Radix rubiginosa* (Michelin, 1831). In a tropical pond in the Lily House (TW). Though more elongate and pointed than usual, the identification was confirmed by DNA (BR).
Physidae
Physella acuta (Draparnaud, 1805). European physa. Orchid House (TW).
Planorbidae
**Planorbella ?duryi* (Wetherby, 1879). Seminole rams-horn. In a tropical pond in the Lily House (TW). The specimens match the DNA of a *Planorbella* species in culture from the aquarium trade, which is perhaps *P. duryi* (BR).
Streptaxidae
**Streptostele musaecola* (Morelet, 1860). In a "moist hothouse" (AS): this is believed to be the first British record (BR); Begonia House and Palm House (TW).
Subulinidae
**Allopeas clavulinum* (Potiez & Michaud, 1838). Orchid House (TW).

Pelecypoda (bivalves)
Sphaeriidae
Pisidium indet. Pea mussel. New pond beside Kibble Palace (Anon., RSPB, 2017).

The full list of species recorded in the Gardens, can be seen at www.gnhs.org.uk/biodiversity/GBG_splist.pdf which also gives the years when each species was first and last seen. It would seem worthwhile looking for the species on that list that have "Latest" dates in the 20th century, though some may have been lost because of habitat change, or through reconstruction of the various ponds. It is also worth noting that some quite common species, such as *Arianta arbustorum* (Linnaeus, 1758) and *Trochulus hispidus* (Linnaeus, 1758), are not listed there.

CRUSTACEA
An account of *Arcitalitrus dorrieni* (Hunt, 1925) is presented separately in this issue of *The Glasgow Naturalist* (Weddle, 2021). Otherwise, little has changed by way of crustacean records since the 1999 account (Hancock, 1999). The only other addition is a freshwater shrimp (*Gammarus* sp.) found in the new pond beside the Kibble Palace in 2015 (Glasgow Museums BRC). The remaining species in the 1999 list are mainly isopods (woodlice) many of which seem not to have been recorded in the Gardens for years; there is no reason to doubt their continuing presence, though, as for the molluscs, it would be useful to obtain more recent records.
The full list of crustacean species recorded in the Gardens, with the years when they were first and last

seen, can be found in the species list given at the end of the Molluscs section above

With regard to the molluscs, thanks are due to Adrian Sumner and Tom Walker for many of the new records; to Maggie Reilly and Geoff Hancock for looking out specimens of *Subulina* in the Hunterian Museum, Glasgow; and to Ben Rowson (National Museum of Wales) who identified many of TW's specimens and made helpful comments. I am grateful also to Glasgow Museums Biological Records Centre for producing the full species lists of both molluscs and crustaceans and for details of some of the individual crustacean records that are cited.

REFERENCES

Hancock, E.G. (1999). Hidden Wildlife: the resident population of invertebrates. *The Glasgow Naturalist* 23(4), 59-64.

Weddle, R.B. (2021). The landhopper *Arcitalitrus dorrieni* (Crustacea: Amphipoda) in Glasgow Botanic Gardens, Scotland. *The Glasgow Naturalist* 27(3), 92-93. https://doi.org/10.37208/tgn27313

---

https://doi.org/10.37208/tgn27309

Increased observations of comma butterflies in Glasgow Botanic Gardens and south-west Scotland

C.J. McInerny

School of Life Sciences, University of Glasgow, Glasgow G12 8QQ

E-mail: chris.mcinerny@glasgow.ac.uk

The comma butterfly (*Polygonia c-album*) has a long history in Scotland, being present in southern areas before a decline during the early 19th century that resulted in its extinction; this loss reflected a contraction in range across the U.K., where the species became rare and localised (Thomas & Lewington, 2010). However, since the early 20th century, the trend reversed with the comma increasing its British distribution. This resulted in a re-colonisation of Scotland, with individuals observed throughout the south and central parts of the country, particularly in the east, and fewer in the west and north (Futter *et al.*, 2006; Sutcliffe, 2009; NBN, 2020). The underlying reasons for these dramatic fluctuations in the species' fortunes are not understood, although climate change, resulting in milder winters, is thought to have played a role in the more recent re-colonisation (Thomas & Lewington, 2010).

The species was first observed in the Glasgow area during 2007, being found at Mugdock Country Park, Milngavie, just north of the city (Sutcliffe, 2009). Several commas were also noted during the same year in South Lanarkshire at Motherwell, Hamilton and East Kilbride (Hancock, 2008). Subsequently, it has been seen to the south and the east of Glasgow each year, with increasing numbers in the city from 2017, and recorded even further north and west to Bute and Kilcreggan, both Argyll & Bute, Gourock, Inverclyde, and Loch Lomond, Stirlingshire (Fig. 1).

The comma was first detected in Glasgow Botanic Gardens when one was seen next to the Kibble Palace on 20th March 2016 (S. Shanks, pers. comm.). The next was observed on 14th April 2019 in the medicinal/herbal garden near to common hop (*Humulus lupulus*), a food plant, though no caterpillars were subsequently found. In April 2020 three commas were found on a clear-felled south-facing slope in the Arboretum next to the River Kelvin (Fig. 2). The first was observed on 16th April, with others noted on 18th and 21st April. Digital photographs revealed that these were three different individuals. That all of these five butterflies were present early in the season, during March and April, suggests that they had over-wintered nearby; adult commas hibernate on trees with their cryptic shape and colouration offering excellent camouflage.

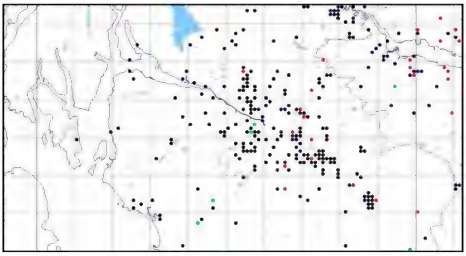

Fig. 1. Map illustrating the colonisation by the comma (*Polygonia c-album*) butterfly of the Glasgow area and south-west Scotland. Black dots (•) indicate records 2015 to 2019, blue dots (•) 2010 to 2014, red dots (•) 2005 to 2009, yellow dots (•) 1995 to 2004, green dots (•) <1995. Grid = 10 km. Data and mapping by Scott Shanks (Glasgow & South West Scotland branch of Butterfly Conservation).

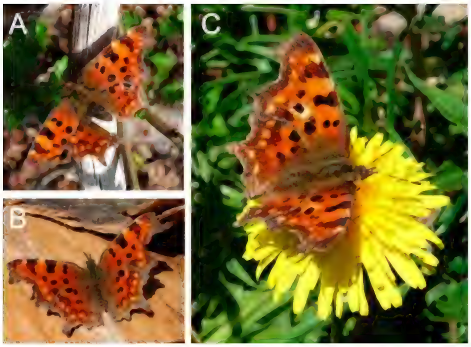

Fig. 2. Comma (*Polygonia c-album*) butterflies, Glasgow Botanic Gardens, Scotland, April 2020. Forewing length *ca.* 25 mm. Three different individuals were observed in the same area near the River Kelvin: (A) on 16th, (B) on 18th, and (C) on 21st April 2020. (Photos: C.J. McInerny)

The three commas in 2020 were observed in a restricted area of the slope, alongside small white (*Pieris rapae*), orange-tip (*Anthocharis cardamines*) and peacock (*Aglais io*) butterflies. Each behaved territorially, chasing and competing with the peacocks, suggesting that if mates were found that they would reproduce in the vicinity. Suitable food plants for the larval stage, such as common nettle (*Urtica dioica*), goat willow (*Salix caprea*) and downy birch (*Betula pubescens*), are all present nearby.

This increase in observations of commas in Glasgow Botanic Gardens reflects the colonisation of the area and region by the species (Fig. 1). Others have been observed nearby in Glasgow since 2017, with records from Kelvingrove Park, Partick, the Kelvin Walkway, Ruchill Park and Dawsholm Park/Garscube Estate. It will be fascinating to see if this increase continues in the future, and if evidence of local breeding is discovered in the city, through the presence of eggs or larvae.

I acknowledge the very helpful assistance of Scott Shanks, and the Glasgow & South West Scotland branch of Butterfly Conservation, in providing many of the records summarised in this Short Note, and for creating the map shown in Fig. 1.

REFERENCES

Futter, K., Sutcliffe, R., Welham, D., Welham, A., Rostron, A.J., Mackay, J. *et al.* (2006). *Butterflies of South West Scotland*. Argyll Publishing, Glendaruel.

Hancock, L. (2008). Comma *Polygonia c-album* L. at Chatelherault, Hamilton. *The Glasgow Naturalist* 25(1), 99-100.

National Biodiversity Network (NBN) Atlas (2020). http://www.nbnatlas.org Accessed 17th May 2020.

Sutcliffe, R. (2009). Recent changes in the distribution of some Scottish butterflies and the arrival of new species in Scotland. *The Glasgow Naturalist* 25(2), 5-12.

Thomas, J. & Lewington, R. (2010). *The Butterflies of Britain and Ireland*. British Wildlife Publishing, Gillingham, Dorset.

The Glasgow Naturalist (2021) Volume 27, Part 3, 97-118

SHORT NOTES

https://doi.org/10.37208/tgn27324

Unusual aquatic vertebrates in the Firth of Forth, Scotland, during 2020: swordfish and northern bottlenose whales

C.J. McInerny[1] & K. Hoey[2]

[1]School of Life Sciences, University of Glasgow, Glasgow G12 8QQ
[2]23 Dempsey Road, Bellshill, North Lanarkshire ML4 2UF

[1]E-mail: chris.mcinerny@glasgow.ac.uk

During 2020 there were two exceptional observations of aquatic vertebrates in the Firth of Forth, with both creatures seen off Lothian. This Short Note describes these events.

The first observation was of a swordfish (*Xiphias gladius*), the fourth live record of the species in Scottish waters (Birdguides, 2020; British Marine Life Study Society, 2021). It was first reported off Musselburgh in early July but was subsequently relocated 3 km to the east at Joppa on 3rd July, where it was seen until at least the 15th (Fig. 1). The swordfish would come in close at high tide, sometimes just 100 m from the shore, but was also seen further offshore when it appeared to hunt.

Fig. 1. Swordfish (*Xiphias gladius*), Joppa, Lothian, Scotland, 7th July 2020. (Photos: D. Morrison)

Swordfish are large, migratory, predatory fish characterised by a long, flat, pointed bill, and a prominent dorsal fin and tail, which can been seen above water when the fish swims near the surface (Fig. 1). They can grow up to 3 m in length and 650 kg in weight; this was the approximate size of the Joppa individual. The species has a cosmopolitan distribution, present in tropical and temperate areas of the Atlantic, Pacific, and Indian Oceans, being found from near the surface to depths of around 500 m (Froese & Pauly, 2021). However, it is rare in the North Atlantic, with just five records elsewhere in the U.K., all in the Bristol Channel (NBN Atlas, 2021), and four in Scottish waters: Firth of Lorne, Argyll, October 1996; Loch Long, Argyll, 15th August 1997 (shoreline corpse); River Forth at Alloa, Clackmannanshire, 4th October 2009; and Seagreen offshore wind farm, off Montrose, Angus, August 2019 (Birdguides, 2020; British Marine Life Study Society, 2021).

The second observation was of two northern bottlenose whales (*Hyperoodon ampullatus*) seen off South Queensferry on 25th August (Fig. 2). They were watched swimming east out of the Firth by the authors, just east of the Forth Bridge.

Northern bottlenose whales are endemic to the North Atlantic where they are a deep-water cetacean species with a fragmented distribution (Hooker & Baird, 1999; Gowans *et al.,* 2001; Whitehead & Hooker, 2012). Thus they are rarely seen in Scottish coastal waters with just over 20 records since 2000 (NBN Atlas, 2021), although up to five were present in the Firth of Clyde during the summer and autumn of 2020 (see O'Reilly & Payne, 2021). Furthermore, the U.K. Cetacean Strandings Investigation Programme database indicates that there have been 52 stranded northern bottlenose whales in Scotland since 1989 (N. Davison, pers. comm.).

The Queensferry whales were seen during very inclement weather with heavy rain and north-east force 6-8 winds. These conditions resulted in pelagic seabirds such as 17 long-tailed skuas (*Stercorarius longicaudus*), two pomarine skuas (*S. pomarinus*) and three sooty shearwaters (*Ardenna grisea*), normally only seen in the open ocean, also being observed in the upper Firth of Forth on 25th August at the same site. Thus this severe weather may explain the presence of the whales. However, it has been suggested that human activities, in particular military sonar signals, are affecting whale behaviour (Parsons, 2017; Wensveen *et al.*, 2019), which might account for their presence close to land and in shallow water.

We thank Dennis Morrison for use of his images shown in Fig. 1.

Fig. 2. Northern bottlenose whale (*Hyperoodon ampullatus*), one of two, South Queensferry, Lothian, Scotland, 25th August 2020. These cetaceans were identified by their size, colour, bulbous foreheads, beaks, and long flat backs with a small falcate fin two-thirds of the way towards the tail. (Photos: K. Hoey)

REFERENCES

Birdguides (2020). Second-ever swordfish confirmed from Scottish waters. https://www.birdguides.com/news/second_ever_swordfish-confirmed-from-scottish-waters/

British Marine Life Study Society (2021). *Swordfish and Blue Marlin Reports (British Seas).* http://glaucus.org.uk/Swordf.htm Accessed 9th March 2021.

Froese, R. & Pauly, D. (Editors) (2021). *FishBase.* https://www.fishbase.de/summary/Xiphias-gladius.html

Gowans, S., Whitehead, H. & Hooker, S.K. (2001). Social organization in northern bottlenose whales, *Hyperoodon ampullatus*: not driven by deep-water foraging? *Animal Behaviour* 62, 369-377. https://doi.org/10.1006/anbe.2001.1756

Hooker, S.K. & Baird, R.W. (1999). Deep-diving behaviour of the northern bottlenose whale, *Hyperoodon ampullatus* (Cetacea: Ziphiidae). *Proceedings of the Royal Society of London B: Biological Sciences* 266, 671-676. https://doi.org/10.1098/rspb.1999.0688

National Biodiversity Network (NBN) Atlas (2021). http://www.nbnatlas.org Accessed 24th January 2021.

O'Reilly, M. & Payne, A.P. (2021). Bottlenose whales in the Clyde Sea Area, Scotland in 2020. *The Glasgow Naturalist* 27(3), 108-111.

Parsons, E.C.M. (2017). Impacts of navy sonar on whales and dolphins: now beyond a smoking gun? *Frontiers in Marine Science* 4, 295. https://doi.org/10.3389/fmars.2017.00295

Wensveen, P., Isojunno, S., Hansen, R.R., von Benda-Beckmann, A.M., Kleivane, L., van IJsselmuide, S. *et al.* (2019). Northern bottlenose whales in a pristine environment respond strongly to close and distant navy sonar signals. *Proceedings of the Royal Society B: Biological Sciences* 286, 20182592. https://doi.org/10.1098/rspb.2018.2592

Whitehead, H. & Hooker, S.K. (2012). Uncertain status of the northern bottlenose whale *Hyperoodon ampullatus*: population fragmentation, legacy of whaling and current threats. *Endangered Species Research* 19, 47-61. https://doi.org/10.3354/esr00458

https://doi.org/10.37208/tgn27304

Behaviour of a lone female honey-buzzard on breeding grounds in central Scotland

C.J. McInerny[1] & K.D. Shaw[2]

[1]School of Life Sciences, University of Glasgow, Glasgow G12 8QQ
[2]13 Chalmers Brae, Anstruther, Fife KY10 3BY

[1]E-mail: chris.mcinerny@glasgow.ac.uk

The honey-buzzard (*Pernis apivorus*) is a rare and elusive breeder in Scotland (McInerny & Shaw, 2019). We have been monitoring the species in central Scotland for the past 30 years and studying it intensely since 2008 (McInerny & Shaw, 2018). Our work has been largely based on field observations of birds, but in recent years we have combined this with nest studies using camera traps. We work closely with Forestry and Land Scotland (FLS) and hold disturbance licences for honey-buzzard in the area and beyond.

An essential part of the project is identifying occupied

territories and potential breeding pairs. The process of establishing breeding pairs and nest locations is complicated by non-breeding birds which can be present in higher numbers than breeders (Clements, 2005; Shaw *et al.*, 2017; McInerny *et al.*, 2018a).

The first active nest that we located was in east central Scotland during 2018. The male of this pair was known to us from previous years and named by us as *"Shorty"*. He was pale grey in colour, in our experience the most common colour form of honey-buzzard observed in central Scotland (Shaw *et al.*, 2019). By mid-May he was usually one of the first birds to return to the breeding areas and was visible throughout the season, often interacting with other males. The female of this pair was thought to be *"Bournville"*, named by us due to her dark brown plumage (McInerny *et al.*, 2018a; McInerny *et al.*, 2018b). This, however, was never established conclusively, as she was extremely difficult to observe; two other females were also seen close to the nest during 2018.

Late in the 2018 breeding season we found the nest in the crown of a very mature Douglas fir (*Pseudotsuga menziesii*) that had been planted during 1974 (FLS pers. comm.) in thick, established, coniferous woodland, close to an old ride. This tree position was inconvenient for camera traps but our partners in the project, FLS, placed one on a nearby tree. The pair successfully reared two young that were photographed on the nest (McInerny *et al.*, 2018b). No adults were seen in the nest images, probably because it was late in the season.

Two cameras were placed in trees next to this same nest in early May 2019 before the arrival of birds. Soon after the breeding season started it was suspected that *Shorty* had not returned. Furthermore, a pair of common buzzards (*Buteo buteo*) had moved closer to the honey-buzzard's nest that we had located, perhaps resulting in the pair moving elsewhere nearby. We searched the surrounding area for the new nest without success, although an active nest in an adjacent territory of honey-buzzards named by us as "*Turnberry"* and "*Whiteshaft"* was discovered that produced two young, with a camera trap installed that recorded these (McInerny *et al.*, 2020). A third unused nest was discovered in another territory on 31st July, most likely the 2017 nest used by the pair named by us as "*Shakespeare"* and "*Anne"* (McInerny *et al.*, 2018a).

When all the honey-buzzards had left the area at the end of the breeding season, FLS retrieved the cameras in mid-October. It was only then that we understood the breeding outcome during 2019 of the Douglas fir nest. A female honey-buzzard, not previously known to us, returned to the nest on 16th May. Such an early arrival date for a female suggests that she was an older bird returning to a previously used nest on an established territory. She remained on the nest intermittently for several days but did not lay a fresh branch until 25th May; honey-buzzards routinely refurbish their old nests, usually with greenery and new sticks (Hardey *et al.*, 2013; McInerny *et al.*, 2020). Following this there was an active period of nest building with more fresh branches added from 27th to 29th May (Figs. 1, 2), after which she was not seen again. Interestingly, no male honey-buzzard was observed at the nest all season, and so it seems likely that the female departed having not found a mate. The nest was, however, visited by other bird species and mammals after the female honey-buzzard had left: a young female northern goshawk (*Accipiter gentilis*) (8th June), jays (*Garrulus glandarius*), wood pigeons (*Columba palumbus*), red squirrels (*Sciurus vulgaris*), and a pine marten (*Martes martes*) (G. Mason, pers. comm.). Jays were recorded visiting while the female honey-buzzard was on the nest, at times mobbing her (Fig. 2).

Fig. 1. Female honey-buzzard (*Pernis apivorus*), central Scotland, 27th May 2019. By this date she had deposited just one fresh branch on the nest. (Photo: G. Mason, C. French & M. Rafferty)

Fig. 2. Female honey-buzzard (*Pernis apivorus*), central Scotland, 28th May 2019. By the following day, she had placed a number of fresh branches on the nest. Note the flying jay (*Garrulus glandarius*), which had been mobbing her. (Photo: G. Mason, C. French & M. Rafferty)

The 2019 breeding season, unlike the previous four years, was challenging for honey-buzzards in central Scotland, with fewer pairs and non-breeders. Our visual observations and the camera trap images indicate that *Shorty* and probably *Bournville* did not return to the study area. Honey-buzzard populations in the north of the U.K. are thought to be less stable than populations in the south (R. Clements, pers. com.) resulting in fluctuations in numbers. Such fluctuations reflect the observation that the species is a long-distance migrant from Africa. At least during 2019 the reduced numbers

were unlikely due to food shortages of the main prey items which are wasp larvae (Hymenoptera) and amphibians, as the other nest in the adjacent territory was well supplied, with the pair rearing two young (McInerny *et al*., 2020).

A combination of detailed observations and camera trap images reveal a fascinating insight into honey-buzzard nesting biology, which is little understood on British breeding grounds. Two cameras in nearby trees are an advantage. Cameras should be installed in early May and set to last until mid-September. Many honey-buzzard nests in conifers are extremely difficult to find being placed in one of two positions: in the crown, or high up next to the trunk (Hardey *et al.*, 2013). The latter are more convenient for camera positioning. Finally, it is important to emphasise that all work should be carried out under licence, and with the landowner's permission.

We thank G. Mason and C. French (Forestry and Land Scotland), and M. Rafferty (Central Scotland Raptor Study Group) for installing and operating the camera trap. We are grateful to Ali Little and Kenny Little who, along with KDS and Forestry and Land Scotland staff carried out most of the nest searching. We thank a reviewer for improvements to the text. To support the 2019 work CJMcI received a grant from the Glasgow Natural History Society, Professor Blodwen Lloyd Binns Bequest; and KDS received a grant from the Scottish Ornithologists' Club.

REFERENCES

Clements, R. (2005). Honey-buzzards in Britain. *British Birds* 98, 153-155.

Hardey, J., Crick, H., Wernham, C., Riley, H., Etheridge, B. & Thompson, D. (2013). *Raptors: a Field Guide for Surveys and Monitoring*. (3rd edition). The Stationery Office (TSO), Scotland.

McInerny, C.J. & Shaw, K.D. (2018). Observations on the 'wing-clapping' aerial display of honey-buzzards in central Scotland. *British Birds* 111, 226-227.

McInerny, C.J. & Shaw, K.D. (2019). The honey-buzzard in Scotland: a rare, secretive and elusive summer visitor and breeder. *The Glasgow Naturalist* 27(1), 20-26. https://doi.org/10.37208/tgn27103

McInerny, C.J., Shaw, K.D., Little, A., Little, K., Hoey, K., Gibb, K. & Kerr, B. (2018a). Honey-buzzards in central Scotland: observations and comparisons from two study areas during 2017. *Scottish Birds* 38, 15-29.

McInerny, C.J., Shaw, K.D., Hoey, K., Little, A., Little, K., Gibb, K. *et al.* (2018b). Honey-buzzards in central Scotland during 2018 - a different breeding year. *Scottish Birds* 38, 308-313.

McInerny, C.J., Shaw, K.D., Mason, G., Little, A. & Little, K. (2020). Observations on nesting honey-buzzards in central Scotland during 2019. *Scottish Birds* 40, 72-75.

Shaw, K.D., McInerny, C.J., Little, A., Little, K., Nadin, J.S. & Goater, R. (2017). An exceptional season at a central Scotland honey-buzzard study area. *Scottish Birds* 37, 3-13.

Shaw, K.D., McInerny, C.J., Gibb, K. & Hoey, K. (2019). Identification of honey-buzzards on Scottish breeding grounds. *Scottish Birds* 39, 68-74.

https://doi.org/10.37208/tgn27302

Kames Bay, Isle of Cumbrae, Scotland: unexplored aspects of a Site of Special Scientific Interest

P.G. Moore

32 Marine Parade, Millport, Isle of Cumbrae
KA28 0EF

E-mail: p.geoff.moore@gmail.com

Kames Bay, Millport, Isle of Cumbrae, Scotland (Fig. 1) is one of the classic sandy beaches of the world. Probably more has been published on the identity, biology and distribution of macrofauna and meiofauna living there than on that of almost any other beach (King & Elmhirst, 1914; Stephen, 1928, 1929, 1931, 1932, 1938, 1945, 1953; Elmhirst, 1931, 1932; Nicholls, 1935, 1939; Watkin, 1938, 1939, 1941, 1942; Dixon, 1944; Clark & Milne, 1955; Smith, 1955; Ansell, 1961; Ansell & Trevallion, 1967; Mauchline, 1967; Ansell, 1969; Corey, 1969; McIntyre, 1970; Barnett, 1971; Ansell, 1972; Barnett & Watson, 1986; Powell & Moore, 1991; Moore & Beare, 1993; Beare & Moore, 1996, 1997, 1998; Cowie & Hannah, 2002, 2006; Moore, 2017).

Fig. 1. Kames Bay, Millport, Isle of Cumbrae, Scotland, 22nd March 2020, showing the glistening area of wetted sand on a receding tide revealed after two dry days but extensive rainfall in the previous weeks, with freshwater draining-up through the beach. (Photo: J. Moore)

For generations fieldwork classes have used this beach for practical and project work based at the Millport Marine Station (first under the Scottish Marine Biological Association (SMBA), then as the University Marine Biological Station Millport (UMBSM), and now as the Field Studies Centre Millport (FSCM)). Its designation as a Site of Special Scientific Interest (SSSI) was based on these educational considerations, but its uniqueness vis-à-vis its salinity conditions should guarantee such status. Intelligent decision-making about how best to manage SSSIs, and coasts in general, in a

sensitive and sustainable way in order to conserve biodiversity, requires basic science at the heart of an Integrated Coastal Zone Management (ICZM) policy.

The physical environment of Kames Bay has been known since the mid-1950s to be particularly interesting in terms of the freshwater upwelling that percolates through its upper regions (though this may occur to varying degrees down its whole extent). Rainfall from the island's catchment is channelled southwards along the underlying Great Cumbrae Fault – a geological feature that is responsible for the position of the embayment in the first place – until it surfaces through the beach (Smith, 1955). A thorough analysis of the physical environment of the beach, or its seasonal variability, has not been published (apart from extensive *in situ* temperature recordings by P.R.O. Barnett; see Barnett & Watson, 1986), although student classes have habitually sampled its physical properties.

Salinity is well known as a key environmental determinant in many aquatic ecosystems (Kinne, 1971), from rockpools (Daniel & Boyden, 1975; Morris & Taylor, 1983; McAllen *et al.,* 1998) to estuaries and lagoons (Barnes, 1996). However, little attention has been paid to the role of brackish water inside the beach at Kames Bay, which is needed because of its possible role in affecting macrofauna and other organisms on and within it. A clearer understanding of the salinity distribution in the beach aquifer would provide context for interpreting the long history of associated biological measurements.

Freshwater is often assumed to run-off beach surfaces with little impact on underlying salinity conditions in the sand (Reid, 1930; Hayward, 1994). Thus, Brown & McLachlan (1990) stated that "dramatic changes in beach water salinity seldom occur" (see also Barrett, 1974); but on Kames Bay, where brackish-water conditions prevail underground below Mean High Water Neap Tide (MHWN) level in an otherwise fully marine locality, they do (Smith, 1955; Hayward, 1994). Kames Bay thus merits particular consideration. As stressed by Eltringham (1971) "the work at Kames Bay ... shows that under certain unusual conditions, salinity can exert a limiting effect on the shore". Large-scale perturbations in surface water salinity have been recorded in the water column off Millport (Thomason *et al.,* 1997), and such stochastic events with a high rate of change of salinity, may have a profound effect on the physiology, behaviour, distribution and abundance of marine organisms (Smith, 1955; Davenport *et al.,* 1975; Hayward, 1994; Barnes, 1996; Little & Kitching, 1996; Santos *et al.*, 1996).

Intermittent low salinity conditions may have a profound, and locally unrecognised, significance in terms of the behaviour and performance of beach-dwelling infauna, even to the extent of modifying productivity (Cowie & Hannah, 2002). Unpublished observations by P.R.O. Barnett (pers. comm.) made offshore in Kames Bay after a period of sustained heavy rainfall some years ago revealed the sublittoral population of the infaunal bivalve *Fabulina* (previously *Tellina*) *fabula* all lying on top of the submerged sand. The suspicion is that groundwater pressure created inimical salinity/thixotropic conditions (in this case even extending to the immediate offshore), prompting their evacuation from the sand. Such a mechanism could result in whole populations of sensitive species being made vulnerable to transportation and/or predation, as also happens after some red tides (Griffith *et al*., 2019). Groundwater discharge from the low-tide line has been shown to lead to the formation of algal blooms (Paerl, 1997). Many sandy beach-dwelling organisms, such as cockles (*Cerastoderma* spp.) and lugworms (*Arenicola* spp.), are economically important, so such data would not only be of academic interest.

The extent to which Kames Bay is unusual in terms of freshwater ingress interstitially is, as yet, to be established and it could well be that all pocket sandy beaches in hard landscape coves and embayments (and even extensive earth-backed sand strands) are generally subject to similar subterranean freshwater percolation influences after heavy rain.

Subterranean interfaces in littoral sediments also have a profound evolutionary significance. Brown & McLachlan (1990) noted that the discharge of groundwater through beaches, as unconfined aquifers, provides a path for the interstitial fauna to evolve landwards to terrestrial and freshwater habitats (Warwick, 1989). These authors note as well that towards the backshore of most sandy beaches a rapid change in interstitial salinity occurs, as percolating seawater gives way to inflowing groundwater. As Jansson (1967) has indicated, however, the importance of rain on interstitial salinity is mainly via increasing groundwater pressure (rather than by overflowing beaches). The up/downshore positioning of the interface between saline and fresh water influences within sandy beach aquifers and its temporal variability under different tidal regimes have been reported elsewhere (Robinson *et al*., 2007; Heiss & Michael, 2014; McAllister *et al.*, 2015, Fig. 1) and these are known to drive microbial geochemical processes (Paerl, 1997; Cowie & Hannah, 2002; McAllister *et al.*, 2015). On Kames Bay, this universal interface is certainly slipped seawards, providing unique opportunities for research generating comparisons with estuarine interfaces (Phillips & Fleeger, 1985; Santos *et al.*, 1996; Robinson *et al*., 2007). Cowie & Hannah (2002) associated the extremely low numbers of naked (non-testate) amoebae in the beach sand at Kames Bay with the unusual salinity regime there, potentially influencing nutrient recycling (McLachlan & Illenberger, 1986; Montagna & Yoon, 1991; Millham & Howes, 1994).

There have been few studies to date of salinity fluctuations within sandy beaches during tidal inundation, with one example being Heiss & Michael (2014). Most published data that exist for salinity variations in sandy beaches (e.g. Jansson, 1966, 1967) have been derived at low tide. Of more than merely academic interest, such a study on Kames Bay would

also assist in the formulation of soundly based advice to policy makers responsible for management and conservation decision-making, especially on sandy beach SSSIs. I hope that some enterprising marine scientist might be intrigued enough to research this topic locally.

I am grateful to Professor James Heiss (Department of Environmental, Earth, and Atmospheric Sciences, University of Massachusetts Lowell, U.S.A.) for his most helpful comments that greatly improved the draft manuscript.

REFERENCES

Ansell, A.D. (1961). Reproduction, growth and mortality of *Venus striatula* (Da Costa) in Kames Bay, Millport. *Journal of the Marine Biological Association of the United Kingdom* 41, 191–215. https://doi.org/10.1017/S0025315400001648

Ansell, A.D. (1969). Association of the amphipod *Acidostoma neglectum* Dahl with the anthozoan *Peachia hastata* Gosse. *Journal of Natural History* 3, 345–347. https://doi.org/10.1080/00222936900770301

Ansell, A.D. (1972). Distribution, growth and seasonal changes in biochemical composition for the bivalve *Donax vittatus* (da Costa) from Kames Bay, Millport. *Journal of Experimental Marine Biology and Ecology* 10, 137–150. https://doi.org/10.1016/0022-0981(72)90099-8

Ansell, A.D. & Trevallion, A. (1967). Studies on *Tellina tenuis* Da Costa. I. Seasonal growth and biochemical cycle. *Journal of Experimental Marine Biology and Ecology* 1, 220–235. https://doi.org/10.1016/0022-0981(67)90016-0

Barnes, R.S.K. (1996). *The Brackish-water Fauna of Northwestern Europe*. Cambridge University Press, Cambridge.

Barnett, P.R.O. (1971). Some changes in intertidal sand communities due to thermal pollution. *Proceedings of the Royal Society of London B*, 177, 353–364. https://doi.org/10.1098/rspb.1971.0035

Barnett, P.R.O. & Watson, J. (1986). Long-term changes in some benthic species in the Firth of Clyde, with particular reference to *Tellina tenuis* da Costa. *Proceedings of the Royal Society of Edinburgh* 90B, 287–302. https://doi.org/10.1017/S0269727000005042

Barrett, J. (1974). *Life on the Sea Shore*. Collins, London.

Beare, D.J. & Moore, P.G. (1996). The distribution, growth and reproduction of *Pontocrates arenarius* and *P. altamarinus* (Crustacea: Amphipoda) at Millport, Scotland. *Journal of the Marine Biological Association of the United Kingdom* 76, 931–950. https://doi.org/10.1017/S0025315400040893

Beare, D.J. & Moore, P.G. (1997). The contribution of Amphipoda to the diet of certain inshore fish species in Kames Bay, Millport. *Journal of the Marine Biological Association of the United Kingdom* 77, 907–910. https://doi.org/10.1017/S0025315400036274

Beare, D.J. & Moore, P.G. (1998). Aspects of the life histories *of Perioculodes longimanus, Pontocrates arcticus* and *Synchelidium maculatum* (Crustacea: Amphipoda) at Millport, Scotland. *Journal of the Marine Biological Association of the United Kingdom* 78, 193–209. https://doi.org/10.1017/S0025315400040029

Brown, A.C. & McLachlan, A. (1990). *Ecology of Sandy Shores*. Elsevier Science Publishers, Amsterdam.

Clark, R.B. & Milne, A.A. (1955). The sublittoral fauna of two sandy bays on the Isle of Cumbrae, Firth of Clyde. *Journal of the Marine Biological Association of the United Kingdom* 34, 161–180. https://doi.org/10.1017/S0025315400008663

Corey, S. (1969). The comparative life histories of three Cumacea (Crustacea): *Cumopsis goodsiri* (van Beneden), *Iphinoe trispinosa* (Goodsir) and *Pseudocuma longicornis* (Bate). *Canadian Journal of Zoology* 47, 695–704. https://doi.org/10.1139/z69-116

Cowie, P.R. & Hannah, F. (2002). Kames Bay – a sandy temperate shore inimical to naked amoebae. *32nd Annual Report of the University Marine Biological Station Millport*, 8-9.

Cowie, P.R. & Hannah, F. (2006). Impact of hydrodynamic disturbance on the growth rates of marine naked amoebae. *Journal of the Marine Biological Association of the United Kingdom* 86, 39–42. https://doi.org/10.1017/S0025315406012835

Daniel, M.J. & Boyden, C.R. (1975). Diurnal variations in physico-chemical conditions within intertidal rockpools. *Field Studies* 4, 161–176.

Davenport, J., Gruffydd, L.D. & Beaumont, A.R. (1975). An apparatus to supply water of fluctuating salinity and its use in a study of salinity tolerances of larvae of the scallop, *Pecten maximus* L. *Journal of the Marine Biological Association of the United Kingdom* 55, 391–409. https://doi.org/10.1017/S0025315400016015

Dixon, A.Y. (1944). Notes on certain aspects of the biology of *Cumopsis goodsiri* (van Beneden) and some other cumaceans in relation to their environment. *Journal of the Marine Biological Association of the United Kingdom* 26, 61-71. https://doi.org/10.1017/S0025315400014454

Elmhirst, R. (1931). Studies on the Scottish marine fauna. The Crustacea of the sandy and muddy areas of the tidal zone. *Proceedings of the Royal Society of Edinburgh* 51,169–175. https://doi.org/10.1017/S0370164600023117

Elmhirst, R. (1932). Quantitative studies between tidemarks. *The Glasgow Naturalist* 10, 56–62.

Eltringham, S.K. (1971). *Life in Mud and Sand*. English Universities Press, London.

Griffith, A.W., Shumway, S.E. & Gobler, C.J. (2019). Differential mortality of North Atlantic bivalve molluscs during harmful algal blooms caused by the dinoflagellate, *Cochlodinium* (a.k.a. *Margalefidinum*) *polykrikoides*. *Estuaries and Coasts* 42, 190–203. https://doi.org/10.1007/s12237-018-0445-0

Hayward, P.J. (1994). *Animals of Sandy Shores*. Richmond Publishing Company, Slough.

Heiss, J.W. & Michael, H.A. (2014). Saltwater-freshwater mixing dynamics in a sandy beach aquifer over tidal, spring-neap, and seasonal cycles. *Water Resources Research* 50, 6747–6766. https://doi.org/10.1002/2014WR015574

Jansson, B.-O. (1966). Microdistribution of factors and fauna in marine sandy beaches. *Veröffentlichen des Instituts für Meeresforschung in Bremerhaven* 2, 77–86.

Jansson, B.-O. (1967). Diurnal and annual variations of temperature and salinity of interstitial water in sandy beaches. *Ophelia* 4, 173–201. https://doi.org/10.1080/00785326.1967.10409619

King, L.A.L. & Elmhirst, R. (1914). Systematic investigation of a sandy shore. *Annual Report of the Scottish Marine Biological Association* 1914, 52–54.

Kinne, O. (1971). Animals. Invertebrates. In: Kinne, O. (Editor). *Marine Ecology, Vol. I, Part 2*, pp. 821–995. Wiley Interscience, London.

Little, C. & Kitching, J.A. (1996). *The Biology of Rocky Shores*. Oxford University Press, Oxford.

McAllen, R., Taylor, A.C. & Davenport, J. (1998). Osmotic and body density response in the harpacticoid copepod *Tigriopus brevicornis* in supralittoral rockpools. *Journal of the Marine Biological Association of the United Kingdom* 78, 1143–1153. https://doi.org/10.1017/S0025315400044386

McAllister, S.M., Barnett, J.M., Heiss, J.W., Findlay, A.J., Macdonald, D.J., Dow, C.L., Luther III, G. W., Holly, A.M. & Chan, C.S. (2015). Dynamic hydrologic and biogeochemical processes drive microbially enhanced iron and sulfur cycling within the intertidal mixing zone of a beach aquifer. *Limnology and Oceanography* 60(1), 329–345. https://doi.org/10.1002/lno.10029

McIntyre, A.D. (1970). The range of biomass of intertidal sand, with special reference to the bivalve *Tellina tenuis*. *Journal of the Marine Biological Association of the United Kingdom* 50, 561–575. https://doi.org/10.1017/S0025315400004884

McLachlan, A. & Illenberger, W. (1986). Significance of groundwater nitrogen input to a beach/surf zone ecosystem. *Stygologia* 2, 291-296.

Mauchline, J. (1967). The biology of *Schistomysis spiritus* (Crustacea, Mysidacea). *Journal of the Marine Biological Association of the United Kingdom* 47, 383–396. https://doi.org/10.1017/S0025315400056496

Millham, N.P. & Howes, B.L. (1994). Nutrient balance of a shallow coastal embayment. 1. Patterns of groundwater discharge. *Marine Ecology Progress Series* 112, 155-167. https://doi.org/10.3354/meps112155

Montagna, P.A. & Yoon, W.B. (1991). The effect of freshwater inflow on meiofaunal consumption of sediment bacteria and microphytobenthos in San Antonio Bay, Texas, USA. *Estuarine, Coastal and Shelf Science* 33, 529-547. https://doi.org/10.1016/0272-7714(91)90039-E

Moore, P.G. (2017). A prodigious collembolan 'swarming' event on Kames Bay, Millport. *The Glasgow Naturalist* 26(3), 86-87.

Moore, P.G. & Beare, D.J. (1993). Taxonomic confusion in the genus *Pontocrates* (Crustacea: Amphipoda) and the presence of *P. arcticus* in Britain. *Journal of the Marine Biological Association of the United Kingdom* 73, 609–615. https://doi.org/10.1017/S0025315400033142

Morris, S. & Taylor, A.C. (1983). Diurnal and seasonal variation in physico-chemical conditions within intertidal rock pools. *Estuarine, Coastal and Shelf Science* 17, 339–355. https://doi.org/10.1016/0272-7714(83)90026-4

Nicholls, A.G. (1935). Copepods from the interstitial fauna of a sandy beach. *Journal of the Marine Biological Association of the United Kingdom* 20, 379–405. https://doi.org/10.1017/S0025315400045306

Nicholls, A.G. (1939). Some new sand-dwelling copepods. *Journal of the Marine Biological Association of the United Kingdom* 23, 327–341. https://doi.org/10.1017/S0025315400013928

Paerl, H.W. (1997). Coastal eutrophication and harmful algal blooms: importance of atmospheric deposition and groundwater as new nitrogen and other nutrient sources. *Limnology and Oceanography* 42, 1154–1165. https://doi.org/10.4319/lo.1997.42.5_part_2.1154

Phillips, F.E. & Fleeger, J.W. (1985). Meiofauna meso-scale variability in two estuarine habitats. *Estuarine, Coastal and Shelf Science* 21, 745–756. https://doi.org/10.1016/0272-7714(85)90070-8

Powell, R. & Moore, P.G. (1991). The breeding cycles of females of seven species of amphipod (Crustacea) in the Clyde Sea area. *Journal of Natural History* 25, 435–479. https://doi.org/10.1080/00222939100770291

Reid, D.M. (1930). Salinity interchange between sea-water in sand and overflowing fresh-water at low tide. *Journal of the Marine Biological Association of the United Kingdom* 26, 604–614. https://doi.org/10.1017/S0025315400072982

Robinson, C., Gibbes, B., Carey, H. & Li, L. (2007). Salt-freshwater dynamics in a subterranean estuary over a spring-neap tidal cycle. *Journal of Geophysical Research* 112(C9), 1–15. https://doi.org/10.1029/2006JC003888

Santos, P.J.P., Castel, J. & Souza-Santos, L.P. (1996). Seasonal variability of meiofaunal abundance in the oligo-mesohaline area of the Gironde estuary, France. *Estuarine, Coastal and Shelf Science* 43, 549–563. https://doi.org/10.1006/ecss.1996.0087

Smith, R.I. (1955). Salinity variation in interstitial water of sand at Kames Bay, Millport, with reference to the distribution of *Nereis diversicolor*. *Journal of the Marine Biological Association of the United Kingdom* 34, 33–46. https://doi.org/10.1017/S0025315400008596

Stephen, A.C. (1928). Notes on the biology of *Tellina tenuis* da Costa. *Journal of the Marine Biological Association of the United Kingdom* 15, 683–702.

https://doi.org/10.1017/S0025315400009590
Stephen, A.C. (1929). Studies on the Scottish marine fauna. The fauna of the sandy and muddy areas of the tidal zone. *Transactions of the Royal Society of Edinburgh* 56, 291–306. https://doi.org/10.1017/S0080456800013211
Stephen, A.C. (1931). Notes on the biology of certain lamellibranchs on the Scottish coast. *Journal of the Marine Biological Association of the United Kingdom* 17, 277–300. https://doi.org/10.1017/S0025315400050840
Stephen, A.C. (1932). Notes on the biology of some lamellibranchs in the Clyde area. *Journal of the Marine Biological Association of the United Kingdom* 18, 51–68. https://doi.org/10.1017/S0025315400051298
Stephen, A.C. (1938). Production of large broods in certain marine lamellibranchs with a possible relation to weather conditions. *Journal of Animal Ecology* 7, 130–143. https://doi.org/10.2307/1119
Stephen, A.C. (1945). Molluscan ecology. *Annual Report of the Scottish Marine Biological Association* 1944-45, 14–16.
Stephen, A.C. (1953). Life in some sandy shores. In: Marshall, S.M. & Orr, A.P. (Editors). *Essays in Marine Biology*, pp. 50-72. Oliver & Boyd, Edinburgh.
Thomason, J.C., Hills, J. M. & Bennett, A. (1997). Dynamics of a massive freshwater influx in the Clyde Sea. *Estuarine, Coastal and Shelf Science* 44, 385–393. https://doi.org/10.1006/ecss.1996.0141
Warwick, R.M. (1989). The role of meiofauna in the marine ecosystem: evolutionary considerations. *Zoological Journal of the Linnean Society of London* 96, 229–241. https://doi.org/10.1111/j.1096-3642.1989.tb02258.x
Watkin, E.E. (1938). A revision of the amphipod genus *Bathyporeia* Lindström. *Journal of the Marine Biological Association of the United Kingdom* 23, 211–136. https://doi.org/10.1017/S0025315400054096
Watkin, E.E. (1939). The pelagic phase in the life history of the amphipod genus *Bathyporeia*. *Journal of the Marine Biological Association of the United Kingdom* 23, 467–481. https://doi.org/10.1017/S0025315400014028
Watkin, E.E. (1941). Observations on the night tidal migrant Crustacea of Kames Bay. *Journal of the Marine Biological Association of the United Kingdom* 25, 81–96. https://doi.org/10.1017/S0025315400014284
Watkin, E.E. (1942). The macrofauna of the intertidal sand of Kames Bay, Millport, Buteshire. *Transactions of the Royal Society of Edinburgh* 60, 543–561. https://doi.org/10.1017/S0080456800008838

https://doi.org/10.37208/tgn27314

The discovery of a colony of wood sage plume *Capperia britanniodactylus* (Lepidoptera: Pterophoridae) in West Stirlingshire, Scotland

M. Culshaw* & C.J. McInerny

School of Life Sciences, University of Glasgow, Glasgow G12 8QQ

*E-mail: martinculshaw121@btinternet.com

Plume moths (Pterophoridae) are highly distinctive, thin and unusual looking microlepidoptera. There are 44 species on the British list, all of which have the characteristic posture of standing up on their legs with wings extended at right angles to the body. The wings have long fringes and are cleft into lobes which resemble feathers (Hart, 2011).

On 7th June 2020, MC was looking for the moth dingy shell (*Euchoeca nebulata*), amongst stream-side alder (*Alnus glutinosa*) near Burncrooks Reservoir, West Stirlingshire, Scotland. During the late morning he came across a flat treeless area at the base of a steep rocky crag, facing WSW and bordered by high bracken (*Pteridium* spp.). Within this location were several patches of flowering wild thyme (*Thymus polytrichus*) which drew his eye. On closer inspection he could see a number of small "plume moths" flying above the thyme, seemingly feeding on it. MC was able to net and pot one of these moths. He did not have any detailed texts with him but did photograph the moth with his mobile phone, estimating its size in the process.

On returning home, MC consulted the various literature sources and informed CJM of his finding. His initial putative identification was that of *Oxyptilus parvidactyla* (small plume) based on both size and wing pattern. He had also noted that small plume is known for flying in afternoon sunshine and visiting wild thyme flowers (Sterling & Parsons, 2018).

However, small plume has only rarely been recorded in Scotland (in just three vice-counties: 91, 92 and 103) so this would have represented the first record for central Scotland and the first Scottish observation for at least six years. In consultation with plume moth expert Colin Hart, MC was reminded of the importance of finding the foodplant at the moth's location to confirm the identification, since there are a number of similarly patterned plume moths that cannot be safely separated by wing pattern alone. While an accurate measurement of forewing length (FL) would possibly have been enough to assign the moths to species level, MC had not taken this and so he and CJM resolved to return to the

site to search for the foodplant of small plume (mouse-ear hawkweed *Pilosella officinarum*) and take accurate FL measurements, and better photos.

CJM visited the site on 11th June 2020 during the early afternoon and found at least 23 of the plume moths on wild thyme and took an excellent photograph of one of them (Fig. 1). Both CJM and MC attended the site again on 14th June 2020 but could find no trace of any mouse-ear hawkweed. Instead they found ample wood sage (*Teucrium scorodonia*) growing side by side with the thyme (Fig. 2). MC was able to net and closely examine further individual moths and measured the FL as 9 mm. All of this indicated that the moths were not small plume but were instead the slightly larger *Capperia britanniodactylus* (wood sage plume), an identification subsequently confirmed by Colin Hart. It was estimated that at least 50 moths were present including some copulating pairs.

Fig. 1. Wood sage plume (*Capperia britanniodactylus*), Burncrooks Reservoir, West Stirlingshire, Scotland, 11th June 2020. (Photo: C.J. McInerny)

Fig. 2. Location of a wood sage plume (*Capperia britanniodactylus*) colony, Burncrooks Reservoir, West Stirlingshire, Scotland, 14th June 2020. (A) General view of the site. (B) Wood sage (*Teucrium scorodonia*), which is the host plant of *C. britanniodactylus* and can been seen along with the blue-purple flowers of wild thyme (*Thymus polytrichus*). (Photos: M. Culshaw)

While not as scarce as small plume in Scotland, wood sage plume is nonetheless a notable find, having been recorded in only about half of the Scottish vice-counties, mainly in the east of the country (Cubitt, 2020). Although widely distributed in Britain, it is quite rare in most places and absent from many apparently suitable sites. This finding represents only the second record of the species in VC86 (Stirlingshire) and the first observation of a colony.

Of note is that the published literature suggests that wood sage plume adult moths hide in clumps of the foodplant during the day and are difficult to disturb, preferring to take flight at dusk (Hart, 2011). This contrasts with our observation of many moths flying in the late morning and early afternoon when it was warm, in overcast as well as sunny conditions.

The initial finding on 7th June also indicates a relatively early emergence date for the species, more in keeping with that in southern Britain, although even there the main emergence is normally July. We suggest that this may have been due to the prolonged period of hot weather in central Scotland in May and early June 2020. The location was a "sun trap" with patches of wild thyme and wood sage growing side by side, providing apparently ideal habitat (Fig. 2).

We thank Colin Hart for help in identifying the plume moth.

REFERENCES

Cubitt, M. (2020). *Scottish Micro Moth Distribution Maps*. Butterfly Conservation East Scotland Branch. http://www.eastscotland-butterflies.org.uk/scottishmicros.html Accessed 17th July 2020.

Hart, C. (2011). *British Plume Moths*. British Entomological and Natural History Society, Reading.

Sterling, P. & Parsons, M. (2018). *Field Guide to the Micromoths of Great Britain and Ireland.* Bloomsbury Wildlife, London.

https://doi.org/10.37208/tgn27308

Observations of two species of clearwing moths (Sesiidae) in south-west Scotland during 2019

C.J. McInerny

School of Life Sciences, University of Glasgow, Glasgow G12 8QQ

E-mail: chris.mcinerny@glasgow.ac.uk

The clearwings (Sesiidae) are day flying moths with fragmented and restricted distributions in Scotland and the U.K., although they are likely under-recorded (Waring *et al.*, 2009). They are notable for their Batesian mimicry, both in appearance and behaviour, of various species of wasps (Hymenoptera). Up to 16 species have been recorded in Britain, but with just five being seen in Scotland, and these rarely encountered because of their elusive nature (Randle *et al.*, 2019). However, the

development of pheromone lures has greatly aided their detection (Larsson, 2016; Anglian Lepidopterist Supplies, 2020a).

The Welsh clearwing (*Synanthedon scoliaeformis*) has a very limited distribution across the U.K., observed at just a few sites in England, Wales and Scotland (Randle *et al.*, 2019). In Scotland it has been reported from a location in Sutherland, at Glen Affric, Glen Moriston and Rannoch Moor, all Highland, and the Trossachs, Stirlingshire (Bland, 1991; Barbour & Bland, 1997; Knowler, 2009; Randle *et al.*, 2019).

During both 2017 and 2018 I attempted to detect the species in the Trossachs at various sites near Aberfoyle previously identified by John Knowler using the SCO pheromone (Anglian Lepidopterist Supplies, 2020a), with no success. However, in 2019, on 27th June, on a sunny, warm day a number of individuals came to pheromone at one location. Over the course of two hours, from 8.30-10.30 a.m., up to 100 visitations of Welsh clearwings occurred, in groups of up to four individuals (Fig. 1). The first appeared almost immediately after the pheromone lure was removed from its container and was hung in a gauze bag on a low branch of a birch tree (*Betula* sp.). Individuals or groups would fly towards the lure, briefly "touch" the gauze bag or a nearby branch a few times, and then fly rapidly away. It was not determined whether the same individuals returned multiple times, or if the visits over the period represented different moths; it has been suggested that males can move large distances (Knowler, 2009). But it seems likely that many clearwings were present, with 27th June representing an emergence day for the species in the clement weather.

Fig. 1. Welsh clearwings (*Synanthedon scoliaeformis*), near Aberfoyle, the Trossachs, Stirlingshire, Scotland, 27th June 2019. Forewing length *ca.* 15 mm. The white gauze bag containing the pheromone lure used to attract the moths is visible in three of the images. (Photos: C.J. McInerny)

The thrift clearwing (*Pyropteron muscaeforme*) has a limited distribution in Scotland and is found only in coastal areas in the south-west and north-east, associated with stands of sea thrift (*Armeria maritima*), the moth's foodplant (Randle *et al.*, 2019). Luring with the pheromone HYL (Anglian Lepidopterist Supplies, 2020a) by Martin Culshaw and the author detected one individual on the beach at Brighouse Bay, Kirkcudbright, Dumfries and Galloway on 13th July 2019 at 1 p.m. amongst sea thrift (Fig. 2). Only one was observed, although many beach sites along the Dumfries and Galloway coast with sea thrift were surveyed over the course of two days.

Fig. 2. Thrift clearwing (*Pyropteron muscaeforme*), Brighouse Bay, Kirkcudbright, Scotland, 13th July 2019. Forewing length *ca.* 8 mm. (Photo: C.J. McInerny)

As this Short Note has illustrated, pheromone luring is an effective strategy for identifying locations containing clearwing moths, which would otherwise be extremely difficult to find. Guidance notes have been published on their use (Anglian Lepidopterist Supplies, 2020b), but a brief summary is presented here in the context of south-west Scotland.

An important consideration when searching for moths is knowledge of their flight period, which can be ascertained from published sources, such as Randle *et al.* (2019). Weather conditions are also significant with both of these day flying clearwing moths active in sunny conditions. Light winds are helpful to distribute the pheromone to attract moths, the recommendation being that the pheromone is exposed for 30 minutes at each site, before a negative record is noted.

Finally, ethical considerations are very important to consider when using pheromones, particularly for moth species such as clearwings, some of which are rare and have legal protection (Anglian Lepidopterist Supplies, 2020b). It is strongly recommended that sites are surveyed with pheromone only once in a season, and that precise locations are not advertised by social media or in publications. It is for these reasons that precise locations are not listed in this Short Note, though they have been

lodged with the moth recorders for the appropriate vice-counties.

I would like to acknowledge the inspiration and advice of the late John Knowler, which led me to see the stunning Welsh clearwing; and the companionship and perseverance of Martin Culshaw that allowed our discovery of the thrift clearwing. I also acknowledge the very helpful comments of the reviewer, Paul Tatner, which much improved the text.

REFERENCES

Anglian Lepidopterist Supplies (2020a). https://www.angleps.com/pheromones.php Accessed 17th May 2020.

Anglian Lepidopterist Supplies (2020b). *Guidance Note on the Use of Pheromone Lures for Recording Moths* https://www.angleps.com/A_Brief_Guidance_Note_on_the_use_of_Pheromone_Lures_for_Recording_Moths.pdf

Barbour, D. & Bland, K. (1997). Distribution of the Welsh clearwing *Synanthedon scoliaeformis* in Scotland. *Entomologist's Gazette* 48, 93.

Bland, K. (1991). The Welsh clearwing *Synanthedon scoliaeformis* (Borkhausen) (Lepidoptera: Sesiidae), still present in its Sutherland locality. *Entomologist's Gazette* 42, 184.

Knowler, J.T. (2009). The Welsh clearwing in the Trossachs. *The Glasgow Naturalist* 25(1), 89-90.

Larsson, M.C. (2016). Pheromones and other semiochemicals for monitoring rare or endangered species. *Journal of Chemical Ecology* 42, 853-868. https://doi.org/10.1007/s10886-016-0753-4

Randle, Z., Evans-Hill, L.J., Parsons, M.S., Tyner, A., Bourn, N.A.D., Davis, T. *et al.* (2019). *Atlas of Britain & Ireland's Larger Moths.* Pisces Publications, NatureBureau Ltd., Newbury.

Waring, P., Townsend, M. & Lewington, R. (2009). *Field Guide to the Moths of Great Britain and Ireland.* (2nd edition). British Wildlife Publishing Ltd., Dorset.

https://doi.org/10.37208/tgn27312

Clavigesta purdeyi (Lepidoptera: Tortricidae): a moth new to Scotland

R.B. Weddle

89 Novar Drive, Glasgow G12 9SS

E-mail: richard@canto.plus.com

On July 26th 2018 Alan Winthrop found a micro-moth which he provisionally identified as *Clavigesta purdeyi* (Durrant, 1911) in his greenhouse in Bishopbriggs, East Dunbartonshire, Scotland (Fig. 1). It had probably been attracted into the greenhouse by an ultraviolet light.

A photograph of the specimen was submitted to Dr Mark Young and Nigel Richards who jointly verified it on the grounds of flight time, size, and head colour compared with the similar *Clavigesta posticana, C. turionella* and *C. logaea.* On 12th August 2020, a second specimen occurred in a moth trap at Glasgow Botanic Gardens (pers. obs.). This was a female and was confirmed from the genitalia by Nigel Richards. The list of Scottish micro-moths maintained by Dr Young on behalf of *Butterfly Conservation* did not include this species, which is therefore an addition to the Scottish fauna.

Fig. 1. Pine leaf-mining moth *Clavigesta purdeyi*, Bishopbriggs, East Dunbartonshire, Scotland; forewing length 6 mm. (Photo: Alan Winthrop)

C. purdeyi has been given the common name pine leaf-mining moth; the larva mines the needles of Scots pine (*Pinus sylvestris*), Corsican pine (*P. nigra* subsp. *laricio*), lodgepole pine (*P. contorta*) etc. and is "local" in coniferous woodland in northern England (Sterling *et al.*, 2012). The same source mentions that it seemed to be expanding its range in England, and had been recorded for the first time in Ireland, so its arrival in Scotland is perhaps not unexpected. It is very likely to be present in Dumfries and Galloway and/or the Scottish Borders.

There is a mature stand of pines near to the Bishopbriggs location in Meadowburn, and several long-established mixed woodlands within 1 km, such as Cadder Wilderness plantation, and the woodlands of Cawder House (now surrounding a golf course). Glasgow Botanic Gardens has a collection of various *Pinus* spp.

The sightings fall within the Watsonian Vice-county of Lanarkshire (VC77).

REFERENCE

Sterling, P., Parsons, M., & Lewington, R. (2012). *Field Guide to the Micromoths of Great Britain and Ireland*. British Wildlife Publishing, Dorset.

https://doi.org/10.37208/tgn27320

Bottlenose whales in the Clyde Sea Area, Scotland in 2020

M. O'Reilly[1] & A.P. Payne[2]

[1]Scottish Environment Protection Agency, Angus Smith Building, 6 Parklands Avenue, Eurocentral, Holytown, North Lanarkshire ML1 4WQ
[2]The Thomson Building, Glasgow University, Glasgow G12 8QQ

[1]E-mail: myles.oreilly@sepa.org.uk

The northern bottlenose whale (*Hyperoodon ampullatus*) is the largest of the beaked whales in the European Atlantic, recognised by its size, 7-9 m in length, bulbous forehead and protruding beak (Fraser, 1976; Evans, 1996). They usually live in pods of four to ten individuals in offshore deep waters (Hooker & Baird, 1999), feeding mostly on deep-water squid (especially the armhook squid, *Gonatus fabricii*), but also on a variety of fish and other invertebrates (Martin, 1990; Santos *et al*., 2001). Bottlenose whales migrate north in spring up to Arctic waters around Iceland, Greenland and Spitzbergen and return south in autumn as far as the Bay of Biscay, occasionally venturing further south to Portugal or the Azores (Van den Brink, 1976; Cresswell & Walker, 2001).

In north European waters, bottlenose whales occur mainly from March to October (particularly in the months of August and September), with peak sightings in the Bay of Biscay between May and August, off northern Scotland in July-September, and in the Faroes in early March and again in August-September (Evans *et al*., 2003). In waters adjacent to the U.K. and Ireland, they are primarily found in the Faroe-Shetland Channel, Rockall Trough, and Bay of Biscay, at depths greater than 1,000 m, although they occasionally enter shallower waters (Evans *et al*., 2003). Those that do stray into shallow coastal waters are at risk of becoming disorientated and malnourished, especially if they wander into estuaries or sea lochs, where they cannot find their usual food (Klinowska, 1985).

In the autumn of 2020 several bottlenose whales entered the Clyde Sea Area, appearing at various locations (Fig. 1), where they were observed, photographed, and videoed by numerous members of the public, and tracked by volunteers from the British Divers Marine Life Recue (BDMLR) organisation. Two whales initially appeared in Victoria Harbour, Greenock, on 22nd August (BBC, 2020a). They left the harbour the next day and were seen heading down the Clyde and up into Loch Long. Over the next couple of days the whales were seen in Loch Goil, with video clips online showing

Fig. 1. Sightings and strandings of bottlenose whales (*Hyperoodon ampullatus*) in the Clyde Sea Area, Scotland in 2020.

them breaching. On 15th September two whales were photographed in Kames Bay, Millport and just a couple of days later three whales appeared in Loch Goil. Between 19th and 22nd September three whales (presumably the same ones) were observed nearby at Arrochar in Loch Long.

On 25th September the three whales arrived in Gare Loch where they stayed until the end of the month. The whales attracted numerous visitors to Garelochhead, where they were observed by MOR on three separate days. The whales patrolled the northern end of the loch and appeared in Garelochhead bay roughly every 20-30 minutes. They manoeuvred around and between the various moored vessels, occasionally approaching close enough to shore so that their breath exhalations were clearly audible. Tail-slapping was frequently seen and occasionally one of the whales would breach producing a spectacular splash. Further crowds of onlookers and photographers gathered on the shores as news of the whales spread on social media. Some people boarded the moored vessels from where they were able to get excellent views of the whales as they cruised by. The police launch from the nearby naval base at Faslane kept watch and prevented smaller craft from disturbing the whales. A TV film crew from the BBC Autumnwatch programme even turned up to film the whales (BBC, 2020b).

Concerns about the welfare of the whales grew and the BDLMR organised an attempt to drive the whales out of Gare Loch on 1st October (BBC, 2020c). This appeared to be unsuccessful (BBC, 2020d), which is perhaps not surprising as bottlenose whales appear to be sensitive to man-made noise and will deep-dive to avoid such disturbance (Miller *et al*., 2015). However, within a couple of weeks they seem to have left Gare Loch of their own accord. Two whales were spotted in Loch Long at Arrochar on 13th October and remained in this vicinity for several days. One whale was observed here by APP and photographed tail-slapping and breaching (Fig. 2a-c).

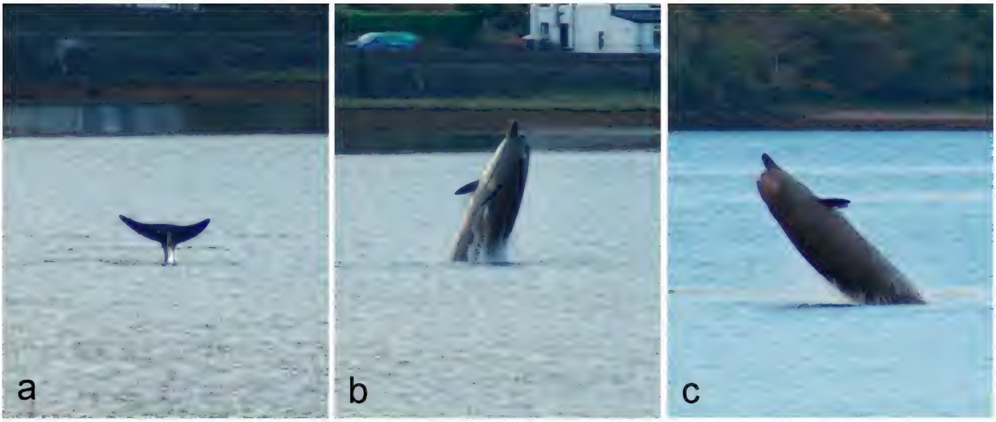

Fig. 2. Bottlenose whales (*Hyperoodon ampullatus*), Arrochar, Loch Long, Scotland, October 2020. (a) Tail-slapping. (b,c) Breaching. (Photos: A.P. Payne)

On 15th October, a bottlenose whale stranded and died at Blairmore in Loch Long. This whale was identified from markings as one of the two seen in Millport in September. On 18th October, a second whale stranded at Portavadie in Loch Fyne. The next day a single whale was seen swimming at Greenock. On 25th October two whales were spotted in the Clyde Estuary, one near Erskine Bridge and another far upstream near Pacific Quay in Glasgow. The following day a whale stranded and died in the Clyde close to the airport. Necropsies of the stranded whales were carried out by scientists from the Scottish Marine Animal Stranding Scheme (SMASS) and details of their findings will be published in due course on the SMASS website (https://www.strandings.org).

With sightings in different places and at different times it is difficult to be certain exactly how many bottlenose whales were in the Clyde Sea Area in autumn 2020. Because they do not have very distinctive markings or coloration patterns, recognising individuals can be difficult (Gowans & Whitehead, 2001). BDLMR observations suggest there may have been five or more whales in the area, of which at least three stranded and died. There were also some other sightings in western Scotland around the same time, with one in Loch Creran, Argyll on 12th October, and one stranded near Stornoway (Eilean Leòdhais) on 13th October.

Sightings of live bottlenose whales around the U.K. and Ireland appear to be sparse. The cetacean status review by Evans *et al.* (2003) shows only about 100 individual whales spotted between 1978 and 2003. Bottlenose whale strandings are also relatively scarce with only 109 records around the U.K. and Ireland between 1800 and 2002 (MacLeod *et al*., 2004). Although there has been a notable increase in cetacean strandings since the 1980s, this appears to be due to increased recording effort (Coombs *et al*., 2019). For bottlenose whales the National Biodiversity Network Atlas for Scotland (NBN, 2020) shows only 16 records, with 13 over the last 20 years. The records include both live sightings and strandings from 11 sites, including Harris, South Uist (both Na h-Eileanan an Iar), Handa Island (Sutherland), Loch Eil, Loch Linnhe (both Argyll), and Wigtown (Dumfries and Galloway) on the west coast and Boyne Bay (Aberdeenshire) and Longannet (Fife) on the east coast. The whale stranded near Longannet in 1988, was found to host some unusual crustacean ectoparasites discussed some years later by O'Reilly (1998). Within the Clyde Sea Area there are just two NBN records for bottlenose whales, a stranding at Port Glasgow in 1896 and a live sighting at Finnieston in September 2009.

However, the NBN records are far from comprehensive. According to Gibson (1976), the bottlenose whale has been a visitor to the Clyde area for around 200 years and is the most frequently seen large cetacean in waters of the Firth of Clyde, with most live animals recorded in late summer or autumn. Furthermore, Gibson lists around 30 bottlenose whale strandings in the Firth of Clyde between 1792 and 1974 with about half of these from within the Clyde Estuary or Gare Loch area. Strandings occurred at Rhu in 1792 and 1941, and within Gare Loch itself in 1863, 1965, and 1974.

Elsewhere in Scotland there are additional old records of bottlenose whales from the Forth cited by McLaren (1981) and more recent records from SMASS Annual Reports, in the Cromarty Firth, 2009 (Brownlow & Reid, 2010), Skye, 2014 (Brownlow *et al*., 2015), and Loch Long (Ardentinny), 2017 (Brownlow *et al*., 2018). The whale washed ashore at Ardentinny in 2017 was visited by MOR (Fig. 3). In 2018 there were 14 strandings of bottlenose whales in northern Scotland, in the Western Isles, Cape Wrath, Orkney, and Shetland. This was part of a highly unusual mass stranding of 118 beaked whales across Scotland, Ireland, Faroes and Iceland (Brownlow *et al*., 2019; Grove *et al*., 2020). Lastly, McInerny & Hoey (2021) reported an observation of two bottlenose whales in the Firth of Forth in August 2020.

Fig. 3. Bottlenose whale (*Hyperoodon ampullatus*) carcass, Ardentinny, Loch Long, Scotland, September 2017. (Photo: M. O'Reilly)

While preparing this note we were informed by Janet Mckillop, a Garelochhead resident, about two bottlenose whales that were seen in Gare Loch in October/November 1965 (see above record from Gibson, 1976). She photographed one of the whales, length just under 7 m, after it stranded at Garelochhead (Fig. 4), while the other whale apparently managed to make its way back out of the loch.

Fig. 4. Bottlenose whale (*Hyperoodon ampullatus*) stranded at Garelochhead, Gare Loch, Scotland, October/November 1965. (Photos: J. Mckillop)

It is evident that bottlenose whales regularly enter Scottish coastal waters, for largely unknown reasons. While there are some previous cases of them lingering at one location for prolonged periods, such as two at Broadford Bay, Skye which remained for over a month during August/September 1998 (Scott, 1999; Weir, 1999), this is fairly unusual. The pod that entered the Clyde Sea Area in 2020 allowed many people to obtain close views of these enigmatic visitors but the event is tarnished by the fact that, for these deep water whales, shallow coastal waters are often a death trap.

Thanks are due to Elaine O'Reilly, Steve Truluck, David Devoy, and Janet Mckillop who all provided helpful information contributing to this short note. The map in Fig. 1 was prepared by Michelle Elliott. An anonymous reviewer provided very useful suggestions, which improved this Short Note.

REFERENCES

BBC (2020a). Whales spotted swimming in Greenock Harbour. https://www.bbc.co.uk/news/av/uk-scotland-53883178

BBC (2020b). Autumnwatch 2020. Episode 7, broadcast BBC2, 5/11/2020. https://www.bbc.co.uk/programmes/m000p3p0

BBC (2020c). Boats herd whales from Gare Loch ahead of military exercise. https://www.bbc.co.uk/news/uk-scotland-glasgow-west-54355189

BBC (2020d). Rescuers' efforts to herd whales from Gare Loch 'unsuccessful'. https://www.bbc.co.uk/news/uk-scotland-glasgow-west-54385843

Brownlow, A., Davison, N. & ten Doeschate, M. (2015). *Scottish Marine Animal Stranding Scheme*. Annual Report 2014, 1 January to 31 December 2014, for Marine Scotland, Scottish Government. https://www.strandings.org/smass/publications/reports/SMASS_Annual_Report_2014.pdf

Brownlow, A., Davison, N. & ten Doeschate, M. (2018). *Scottish Marine Animal Stranding Scheme*. Annual Report 2017, 1 January to 31 December 2017, for Marine Scotland, Scottish Government. https://www.strandings.org/smass/publications/reports/SMASS_Annual_Report_2017.pdf

Brownlow, A., Davison, N. & ten Doeschate, M. (2019). *Scottish Marine Animal Stranding Scheme*. Annual Report 2018, 1 January to 31 December 2018, for Marine Scotland, Scottish Government. https://www.strandings.org/smass/publications/reports/SMASS_Annual_Report_2018.pdf https://doi.org/10.31219/osf.io/qkcwg

Brownlow, A. & Reid, B. (2010). *Marine Mammal Stranding Coordination and Investigation (Scotland)*. Annual Report, 1 January to 31 December 2009, for Marine Scotland, Scottish Government. https://www.strandings.org/smass/publications/reports/SMASS_Annual_Report_2009.pdf

Coombs, E.J., Deauville, R., Sabin, R.C., Allan, L., O'Connell, M., Berrow, S. *et al.* (2019). What can cetacean stranding records tell us? A study of UK

and Irish cetacean diversity over the past 100 years. *Marine Mammal Science* 35, 1527-1555. https://doi.org/10.1111/mms.12610

Cresswell, G. & Walker, D. (2001). *Whales and Dolphins of the European Atlantic, the Bay of Biscay and the English Channel.* Ocean Guides, P & O, Portsmouth.

Evans, P.G.H. (1996). *Guide to the Identification of Whales, Dolphins, and Porpoises in European Seas.* Scottish Natural Heritage, Edinburgh.

Evans, P.G.H., Anderwald, P. & Baines, M.E. (2003). *UK Cetacean Status Review*. Sea Watch Foundation report to English Nature and Countryside Commission for Wales, Oxford.

Fraser, F.C. (1976). *British Whales, Dolphins and Porpoises. A Guide for the Identification and Reporting of Stranded Whales, Dolphins, and Porpoises on the British Coast*. (5th edition). British Museum (Natural History), London.

Gibson, J.A. (1976). The marine mammals of the Clyde Faunal Area. *Western Naturalist* 5, 3-39.

Gowans, S., & Whitehead, H. (2001). Photographic identification of northern bottlenose whales (*Hyperoodon ampullatus*): sources of heterogeneity from natural marks. *Marine Mammal Science* 17, 76-93. https://doi.org/10.1111/j.1748-7692.2001.tb00981.x

Grove, T., Senglat, C., Petitguyot, M., Kosiba, D. & Rasmussen, M.H. (2020). Mass stranding and unusual sightings of northern bottlenose whales (*Hyperoodon ampullatus*) in Skjálfandi Bay, Iceland. *Marine Mammal Science* 2020, 1-9. https://doi.org/10.1111/mms.12689

Hooker, S.K. & Baird, R.W. (1999). Deep–diving behaviour of the northern bottlenose whale, *Hyperoodon ampullatus* (Cetacea: Ziphiidae). *Proceedings of the Royal Society, Series B: Biological Sciences* 266, 671-676. https://doi.org/10.1098/rspb.1999.0688

Klinowska, M. (1985). Interpretation of the UK cetacean strandings records. *Report of the International Whaling Commission* 35, 459-467. Paper no. SC/36/O 9.

MacLeod, C.D., Pierce, G.J., & Santos Vazquez, M.B. (2004). Geographic and temporal variations in strandings of beaked whales (Ziphiidae) on the coasts of the UK and the Republic of Ireland from 1800-2002. *Journal of Cetacean Research and Management* 6, 79-86.

Martin, A.R. (1990). *The Illustrated Encyclopaedia of Whales and Dolphins*. Portland House, New York.

McInerny, C.J. & Hoey, K. (2021). Unusual aquatic vertebrates in the Firth of Forth, Scotland, during 2020: swordfish and northern bottlenose whales. *The Glasgow Naturalist* 27(3), 97-98. https://doi.org/10.37208/tgn27308

McLaren, W.B. (1981). Notes on the stranding of a Bottle-nosed Whale on the mudflats at Skinflats. *Forth Naturalist and Historian* 6, 19-20.

Miller, P.J.O., Kvadsheim, P.H., Lam, F.P.A., Tyack, P.L., Curé, C., DeRuiter, S.L. *et al.* (2015). First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise. *Royal Society Open Science* 2, e140484. https://doi.org/10.1098/rsos.140484

NBN (2020). *National Biodiversity Network Atlas Scotland.* https://scotland-species.nbnatlas.org/species/NBNSYS0000005166 Accessed 6th April 2021.

O'Reilly, M. (1998). Whale-lice (Amphipoda: Cyamidae) and sea lice (Copepoda: Caligidae) from stranded whales in the Firth of Forth. *The Glasgow Naturalist* 23(3), 24-26.

Santos, M.B., Pierce, G.J., Smeenk, C., Addink, M.J., Kinze, C.C., Tougaard, S. & Herman, J. (2001). Stomach contents of northern bottlenose whales *Hyperoodon ampullatus* stranded in the North Sea. *Journal of the Marine Biological Association of the United Kingdom* 81, 143-150. https://doi.org/10.1017/S0025315401003484

Scott, S. (1999). Northern Bottle Nosed Whales off Skye. *British Wildlife* 10, 89-91.

Van den Brink, F.H. (1967). *A Field Guide to the Mammals of Britain and Europe*. Collins, London.

Weir, C.R. (1999). Northern bottlenose whales, Isle of Skye. *Birding Scotland* 2, 12–13.

https://doi.org/10.37208/tgn27303

Herring gull (*Larus argentatus*) damage to razor clam (*Ensis siliqua* and *E. ensis*) shells on the Isle of Cumbrae, Scotland

P.G. Moore

32 Marine Parade, Millport, Isle of Cumbrae KA28 0EF

E-mail: p.geoff.moore@gmail.com

Herring gulls (*Larus argentatus*) are an opportunist species with a catholic diet (Tinbergen, 1953; Hudson & Furness, 1988; Ewins *et al*., 1994; Moore, 2018). They have been reported feeding on razor clams (*Ensis leei,* as "*E. directus*") in the Dutch Wadden Sea (Cadée, 2000; Enners *et al*., 2018). Witnessing them feeding on *E. siliqua* and *E. ensis* near my house in Millport, Isle of Cumbrae, Scotland (NS171547) in April 2020 provided the opportunity for comparative observations.

Both razor clam species are common in sublittoral sand below the adjacent beach at Kames Bay, Millport (Allen, 1962; see Holme, 1951 and Fig. 1 herein for distinguishing features). Herring gulls were seen feeding on both *Ensis* species at three sites: (1) the grass verge in front of my house (this observation being subsequent to my previously finding at the same site dead shells – mostly still articulated – that were below the line of flotsam thrown up on the grass and so had clearly not been deposited by recent storms); (2) a rocky

prominence on the seaward side of the nearby boating pond; and (3) the tide edge during suitable low-tide conditions on the south-east corner of Kames Bay. *Ensis* shells were recovered from all three places from 12th to 22nd April (daily, or when tidally appropriate) and the collection examined for signs of shell damage. It was hoped that damage patterns might provide insight into how herring gulls at this location feed on razor clams.

On 12th April, 11 *E. siliqua* and two *E. ensis* empty shells were collected along a 70 m length of the grass verge; on 21st April nine *E. siliqua* and five *E. ensis* shells were collected from the rocky prominence (where they were accompanied by broken sea urchin (*Echinus esculentus*) tests and considerable guano splattering), and five *E. siliqua* and one *E. ensis* shells were collected from the tide-edge at low tide on the beach but over what period the accumulations had taken place at the first two sites is unknown. The first two sites represented preferred food-processing stations (vigilance posts?) but whether of particular gulls is unknown. One reason why *Ensis* shells might be processed at sites away from the beach became apparent when a herring gull feeding on a newly extracted razor clam at the tide edge was harassed by a great black-backed gull (*L. marinus*) landing alongside it, which was followed by the herring gull flying away with the shell. The herring gulls' initial tendency to open shells at the immediate tide edge would account for sand grains becoming adherent to flesh fragments found remaining stuck to the inside of the recovered empty shells.

Fig. 1. Right valves of the razor clams *Ensis siliqua* (top) and *E. ensis* (bottom) from Isle of Cumbrae, Scotland. Note relative sizes and robustness. (Photo: P.G. Moore)

Most empty shells were orientated with their internal surfaces facing up and the majority (96% of *E. siliqua* and 87% of *E. ensis*) remained articulated. None was deposited on the adjacent hard surface either of the adjacent road (Marine Parade) or pavement, suggesting that the gull (or gulls) that had acquired this proclivity was/were not dropping the shells from a height onto a hard surface in order to break the shells. Similarly on the rocky prominence few shells were smashed. *Ensis* shells are quite brittle so it would be easy to break them in the way that gulls treat other prey items such as mussels (*Mytilus* spp.), sea urchins (Echinoidea) and hermit crabs (Paguridae) (see Moore, 2018), but this seems not to have occurred. Occasional crushed shells were found on hard surfaces around the boating pond (pond-edge walkway, iron man-hole cover) but were most likely the result of children stamping on intact shells.

Dutch herring gulls in the Wadden Sea were able to access razor clams in <40 cm of water by up-ending and seizing the clams' posterior protrusions (Cadée, 2000). Cadée described a characteristic pattern of shell fragmentation of *E. leei* resulting from such predation, caused by the gull shaking the extracted razor clam vigorously after gripping the shell at about the shell's middle, with no hammering involved. Both valves were typically damaged medially as a result, although about a quarter of the shells remained undamaged.

On Cumbrae, *E. siliqua* (Fig. 2) damage was most often (28%) associated with the first quartile of the ventral margin of the right valve (the shell ligament being anatomically "anterior dorsal"). In the pooled sample of 25 *E. siliqua* shells, accumulated between 14th and 22nd April (consistent with tidal conditions) from all three sites, ten (40%) were undamaged, whilst in damaged shells the damage sustained was focused in the anterior quartiles of the shell (Fig. 2; Table 1). This corresponds with the position of the anterior adductor muscle (see Yonge & Thompson, 1976: Figs. 113, 115), the rupture of which would allow swift access to the razor-clam tissue by facilitating shell gape (*E. leei* razor clam flesh is consumed in one or two minutes according to Cadée (2000)). Perhaps because *E. siliqua* is a larger, more robust species its shells suffered less damage than reported for *E. leei*. The size of the fracture (Fig. 2) suggests a strike or a snip with the gull's bill (bill width *ca.* 20 mm; Bob Furness, pers. comm.). It is notable that damage was principally sustained by the right valve (Fig. 2; Table 1) and only one *E. siliqua* shell had both valves damaged. It may be relevant that Feare (1971) showed that oystercatchers exhibited a "right-handed" tendency in the way they prised limpets (*Patella aspera*) off rocks.

Fig. 2. Damage to the first quartile of the ventral margin of the right valves of three razor clams (*Ensis siliqua*) from Isle of Cumbrae, Scotland. (Photo: P.G. Moore)

	Ensis siliqua		*Ensis ensis*	
	Right valve damage: N (%)	**Left valve damage: N (%)**	**Right valve damage: N (%)**	**Left valve damage: N (%)**
1st quartile	7 (28)	4 (16)	0	0
2nd quartile	4 (16)	4 (16)	2 (25)	2 (25)
3rd quartile	1 (4)	4 (16)	3 (38)	2 (25)
4th quartile	0	2 (8)	0	0

Table 1. Summary of damage to razor clam *Ensis siliqua* (N = 25) and *E. ensis* (N = 8) shells from sites at Kames Bay, Isle of Cumbrae, Scotland, April 2020.

Of the smaller *E. ensis* shells (see Holme, 1951 and Fig. 1) that were recovered (N = 8), 50% were undamaged (Table 1). Other individuals had damage extending further along the ventral margins of both valves, suggesting that vigorous shaking by the gull, resulting in damage about the middle of the shell, might characterise the herring gull's processing of *E. ensis*, at least locally, but might not apply to *E. siliqua*. Extraction of the clam from the substratum by gripping the siphons or the posterior margin of the shell might account for the "nibbles" to that margin noted in two *E. siliqua* specimens (Fig. 3), but I have yet to observe a complete cycle of razor shell capture and a gull's initial clam flesh-accessing behaviour.

Fig. 3. Damage to the posterior shell margins of the left valves in two razor clam (*Ensis siliqua*) specimens from Isle of Cumbrae, Scotland. (Photo: P.G. Moore)

REFERENCES

Allen, J.A. (1962). *Fauna of the Clyde Sea Area. Mollusca.* Scottish Marine Biological Association, Millport.

Cadée, G.C. (2000). Herring gulls feeding on a recent invader in the Wadden Sea, *Ensis directus*. *Geological Society of London Special Publication* 177, 459–464. https://doi.org/10.1144/GSL.SP.2000.177.01.31

Enners, L., Schwemmer, P., Corman, A.-M., Voigt, C.C. & Garthe, S. (2018). Intercolony variations in movement patterns and foraging behaviours among herring gulls (*Larus argentatus*) breeding in the eastern Wadden Sea. *Ecology and Evolution* 8, 7529–7542. https://doi.org/10.1002/ece3.4167

Ewins, P.J., Weseloh, D.V., Groom, J.H., Dobos, R.Z. & Mineau, P. (1994). The diet of herring gulls (*Larus argentatus*) during winter and early spring on the lower Great Lakes. *Hydrobiologia* 279, 39–55. https://doi.org/10.1007/BF00027839

Feare, C.J. (1971). Predation of limpets and dogwhelks by oystercatchers. *Bird Study* 18, 121–129. https://doi.org/10.1080/00063657109476305

Holme, N.A. (1951). The identification of British species of the genus *Ensis* Schumacher (Lamellibranchiata). *Journal of the Marine Biological Association of the United Kingdom* 29, 639–647. https://doi.org/10.1017/S0025315400052838

Hudson, A.V. & Furness, R.W. (1988). Utilization of discarded fish by scavenging seabirds behind trawlers in Shetland. *Journal of Zoology* 215, 151–166. https://doi.org/10.1111/j.1469-7998.1988.tb04890.x

Moore, P.G. (2018). On the paddling behaviour of a herring gull. *The Glasgow Naturalist* 26(4), 89–90.

Tinbergen, N. (1953). *The Herring Gull's World: a Study of the Social Behaviour of Birds.* Collins, London.

Yonge, C.M. & Thompson, T.E. (1976). *Living Marine Molluscs*. Collins, London.

https://doi.org/10.37208/tgn27326

Expansion in recorded range of fossorial water voles in Glasgow, Scotland

C.J. McInerny

School of Life Sciences, University of Glasgow, Glasgow G12 8QQ

E-mail: chris.mcinerny@glasgow.ac.uk

The water vole (*Arvicola amphibius*) is a rare mammal throughout Scotland and the U.K. with numbers suffering dramatic declines due to changes in agricultural practices and through predation by introduced American minks (*Neovison vison*) (Rushton *et al.*, 2000; Aars *et al.*, 2001; Telfer *et al.*, 2003; Strachan, 2004; Dean *et al.*, 2016). Thus the colonies in east Glasgow, where large numbers are found, are of national importance, and are unusual in being present in urban grasslands far from water with the voles having a fossorial lifestyle, digging holes and living underground (Stewart *et al.*, 2017; McInerny, 2018; Stewart *et al.*, 2019).

I have been studying the populations of water voles in east Glasgow for a number of years, surveying their distribution during 2018 and 2019. Animals were detected by visual surveys during March, April and May when they were more visible. At this time of the year voles, having been mostly underground through the winter, spend much time feeding on grass near their holes above ground, and are particularly visible due to the short and flattened sward (Fig. 1). Their presence during the surveys was also established by the detection of holes, diggings, pellets and clipped grass, indicative of the species (Stewart *et al.*, 2019). Water voles engage in much digging and excavation in early spring and leave half-consumed grass, making their detection straightforward (Fig. 2).

The surveys over two springs during 2018 and 2019 revealed the presence of fossorial water voles across many parts of east Glasgow (Fig. 3), with animals and diggings located at numerous locations from Bishop Loch (NS687664) in the east to Hogganfield Loch (NS646676) in the west. All were far from water, with many located in public parks, but with others on road verges (Fig. 1B) and neglected ground. This distribution was similar to that noted by others (Stewart *et al.*, 2017; Wijas *et al.*, 2019), although in many areas higher densities were detected and new sites were found. A common feature of the locations of animals and burrows was the absence of management of the ground, with grass always uncut (Stewart *et al.*, 2019). Many such unmanaged areas are found throughout east Glasgow (Fig. 2). Because most of these were monitored for the presence of water voles during the surveys of 2018 and 2019, I believe that the distribution shown in Fig. 3 gives a reasonably accurate impression of their range in east Glasgow during these two years.

Fig. 1. Water voles (*Arvicola amphibius*), Glasgow, Scotland. (A) Black animal, Ruchazie, Glasgow, 23rd March 2018. (B) Brown animal, Easterhouse, 18th April 2019. (Photos: Chris McInerny)

Fig. 2. Evidence of the presence of water voles (*Arvicola amphibius*), Glasgow, Scotland. (A) Burrow entrance and diggings, Cranhill Park, 23rd March 2018. (B,C) Clipped grass at burrow entrances, Ruchill Park, Glasgow, 15th May 2020. Burrow entrances *ca*. 5 cm in diameter. (Photos: Chris McInerny)

Through the spring of 2020 travel restrictions due to the COVID-19 pandemic prevented me from visiting east Glasgow. I was, however, able to monitor areas in the West End of Glasgow near my home during "lock-down" walks. The preferred habitat of water voles, uncut grass verges and neglected land, was surveyed within 3 km of Glasgow Botanic Gardens. Most areas revealed no evidence of animals, but burrows and fresh clipped grass were discovered in Ruchill Park, with at least eight burrows located at different parts of the park (Fig. 2). Ruchill Park is about 7 km west of the nearest fossorial water voles in east Glasgow at Hogganfield Loch (Fig. 4). This is the first time that fossorial water voles have been found in the West End of the city, although animals have occasionally been observed elsewhere in west Glasgow on watercourses (Wijas *et al.*, 2019). These are likely to be the aquatic rather than the fossorial form.

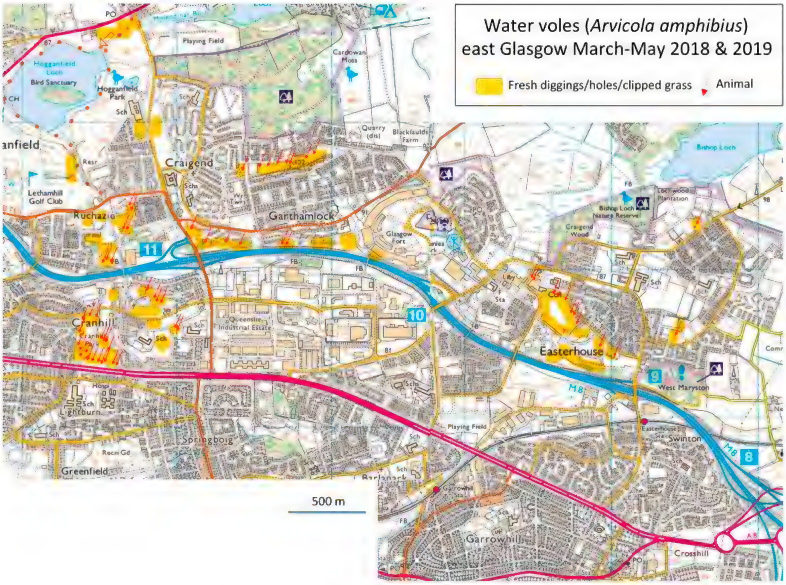

Fig. 3. Water vole (*Arvicola amphibius*) distribution in east Glasgow, Scotland, March-May, 2018 and 2019.

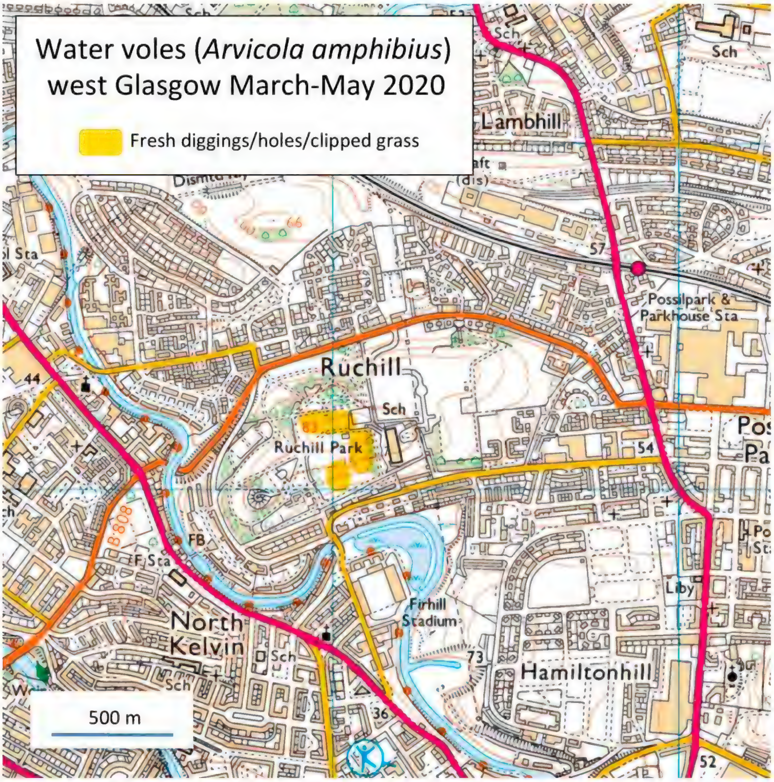

Fig. 4. Water vole (*Arvicola amphibius*) distribution in west Glasgow, Scotland, March-May, 2020.

I have subsequently searched for evidence of fossorial water voles between Ruchill Park and Hogganfield Loch, but with no success. It is therefore unclear how they colonised Ruchill, although being fossorial they may be derived from the large east Glasgow populations. The species distribution has been noted to be patchy elsewhere (Lawton & Woodroffe, 1991), with this being due in some areas to predation by American mink and habitat fragmentation (Rushton *et al.*, 2000). However, these seem unlikely reasons to explain the distribution in Glasgow as much apparently suitable habitat is present throughout the city and American minks are rare to largely absent (Wijas *et al*., 2019; pers. obs.). Predation of fossorial water voles by red foxes (*Vulpes vulpes*) has been reported (Weber & Aubry, 1993). Since Glasgow has a rich population of red foxes, it is possible that this predator may influence the urban water vole distribution. Furthermore, birds of prey such as common buzzard (*Buteo buteo*), common kestrel (*Falco tinnunculus*) and peregrine (*Falco peregrinus*) are all present in the city and have been observed hunting voles (McInerny, 2018), so may play a role.

Finally, it is important to note that a number of sites in east Glasgow where water voles were detected during the 2018 and 2019 surveys are being developed for housing. Trapping of voles was observed and these are presumably moved to other protected sites. Even so, it appears that much habitat occupied by water voles will be lost, which, considering the species' rarity and status in the U.K., is unfortunate, especially when the unusual fossorial behaviour of the Glasgow population is considered.

REFERENCES

Aars, J., Lambin, X., Denny, R., & Griffin, A. (2001). Water vole in the Scottish uplands: distribution patterns of disturbed and pristine populations ahead and behind the American mink invasion front. *Animal Conservation* 4, 187-194. https://doi.org/10.1017/S1367943001001226

Dean, M., Strachan, R., Gow, D. & Andrews, R. (2016). *The Water Vole Mitigation Handbook*. The Mammal Society, London.

Lawton, J.H., & Woodroffe, G.L. (1991). Habitat and the distribution of water voles: why are there gaps in a species' range? *Journal of Animal Ecology* 60, 79-91. https://doi.org/10.2307/5446

McInerny, C.J. (2018). Peregrine hunting water voles in Glasgow. *Scottish Birds* 38, 240-241.

Rushton, S.P., Barreto, G.W., Cormack, R.M., MacDonald, D.W. & Fuller, R. (2000). Modelling the effects of mink and habitat fragmentation on the water vole. *Journal of Applied Ecology* 37, 475-490. https://doi.org/10.1046/j.1365-2664.2000.00504.x

Stewart, R.A., Clark, T.J., Shelton, J., Stringfellow, M., Scott, C., White, S.A. & McCafferty, D.J. (2017). Urban grasslands support threatened water voles. *Journal of Urban Ecology* 3, 1-17. https://doi.org/10.1093/jue/jux007

Stewart, R.A., Jarrett, C., Scott, C., White, S.A. & McCafferty, D.J. (2019). Water vole (*Arvicola amphibius*) abundance in grassland habitats of Glasgow. *The Glasgow Naturalist* 27(1), 10-19. https://doi.org/10.37208/tgn27102

Strachan, R. (2004). Conserving water voles: Britain's fastest declining mammal. *Water and Environment Journal* 18, 1-4. https://doi.org/10.1111/j.1747-6593.2004.tb00483.x

Telfer, S., Dallas, D.F., Aars, J., Piertney, S. B., Stewart, W.A. & Lambin, X. (2003). Demographic and genetic structure of water voles (*Arvicola terrestris*) on Scottish islands. *Journal of Zoology* 259, 23-29. https://doi.org/10.1017/S0952836902003321

Weber, J.M. & Aubry, S. (1993). Predation by foxes, *Vulpes vulpes,* on the fossorial form of the water vole, *Arvicola terrestris scherman,* in western Switzerland. *Journal of Zoology* 229, 553-559. https://doi.org/10.1111/j.1469-7998.1993.tb02656.x

Wijas, B.J., Stewart, R.A. & McCafferty, D.J. (2019). Potential risk of American mink to water vole populations in east Glasgow. *The Glasgow Naturalist* 27(1), 84-86. https://doi.org/10.37208/tgn27122

https://doi.org/10.37208/tgn27311

Fluctuations in annual numbers of flowering bee orchids (*Ophrys apifera*) in South Ayrshire, Scotland

C.J. McInerny

School of Life Sciences, University of Glasgow, Glasgow G12 8QQ

E-mail: chris.mcinerny@glasgow.ac.uk

The bee orchid (*Ophrys apifera*) has a wide range across Europe, the Middle East and North Africa (Harrap & Harrap, 2009). It is present locally throughout England, Wales and Ireland, but is extremely rare in Scotland, having been recorded in only southern areas of the country at about ten locations in Argyll and Bute, Dumfries and Galloway, East Ayrshire, Glasgow, East Lothian and Berwickshire (Laney & Stanley, 2004a, 2004b; Allan & Woods, 1993; Anon., 2017; NBN, 2020; BSBI, 2020).

On 29th June 2014, Darren O'Brien and I discovered bee orchids at a new location in South Ayrshire at Bennane Head Grasslands (NX10508796) (Fig. 1A). This site is an embankment of the A77 road at a coastal location, with large numbers of other orchid species present including green-winged orchid (*Anacamptis morio*), early-purple orchid (*Orchis mascula*), heath fragrant-orchid (*Gymnadenia borealis*) and common spotted-orchid (*Dactylorhiza fuchsii*). The bee orchid site is within Bennane Head Grasslands Site of Special Scientific Interest (SSSI) notified for both its lowland neutral grassland and its population of green-winged orchids (Registers of Scotland, 2020).

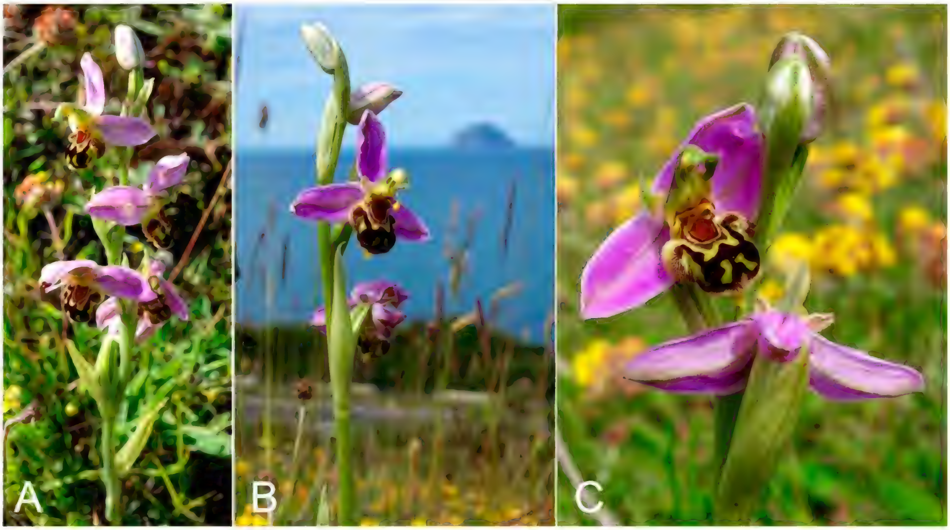

Fig. 1. Bee orchids (*Ophrys apifera*), Bennane Head, South Ayrshire, Scotland. A, 29th June 2014. B,C, 22nd June 2019. (Photos: C.J. McInerny)

On this day we counted 110 flowering spikes of bee orchid on an area of the slope that was particularly bare, little colonised by other vegetation, typical habitat for bee orchids, which are usually found on poor and disturbed ground (Harrap & Harrap, 2009). This is one of the largest counts of bee orchids ever recorded at a site in Scotland. Each subsequent year to 2019, I have returned to Bennane Head and made counts of the flowering spikes, which have fluctuated in numbers (Table 1). Every year the slope where they grew has remained similarly bare, with much open ground and little vegetation growth (Fig. 1B,C).

Year	Number of flower spikes	Date counted
2014	110	29/06
2015	60	01/07
2016	85	03/07
2017	40	01/07
2018	55	30/06
2019	25	22/06

Table 1. Number of bee orchid (*Ophrys apifera*) flower spikes, Bennane Head, South Ayrshire, Scotland, 2014-2019.

Bee orchids live on average 6.6 years (range 5.8-11.2 years) and, though some individual plants can flower in consecutive years, usually they remain dormant for one to two years before flowering again (Harrap & Harrap, 2009). On years when lower numbers of flowering spikes were counted at Bennane Head it appeared that the ground of the slope was particularly dry, with almost no general sward growth, suggesting that low rainfall earlier in the year might explain the smaller numbers of bee orchids flowering in June.

To explore this possibility I interrogated the temperature and rainfall patterns for the region over the period 2014-2019. Data were obtained from the Met Office for the months January to June for each year, before and during the period when the orchids grow a stalk and flower, with these plotted for each year (Fig. 2).

The change in monthly average temperature from January to June appeared similar each year from 2014 to 2019, increasing from 6-8°C to 16-18°C (Fig. 2). This observation suggests that the differences in numbers of flowering plants were not influenced by differences in ambient temperature from January to June.

However, differences were apparent in the amount of monthly rainfall between years, with the highest winter rainfall in January and February 2014, the year when the largest numbers of flowering spikes were counted (Fig. 2); larger spike numbers were also seen in 2016 and 2018 when higher winter rainfall was observed. In contrast, lower winter rainfall was recorded in 2015, 2017 and 2019, the years of smaller spike numbers. It is possible therefore that winter rainfall influences the numbers of bee orchids flowering each year. As part of their development plants appear above ground in late winter as single leaves (Harrap & Harrap, 2009), so it is possible that growth during this season is significant in relation to flowering later in the year. I plan to continue monitoring these beautiful flowers at Bennane Head in the future, to further test if the correlation between flowering spike numbers and increased winter rainfall continues.

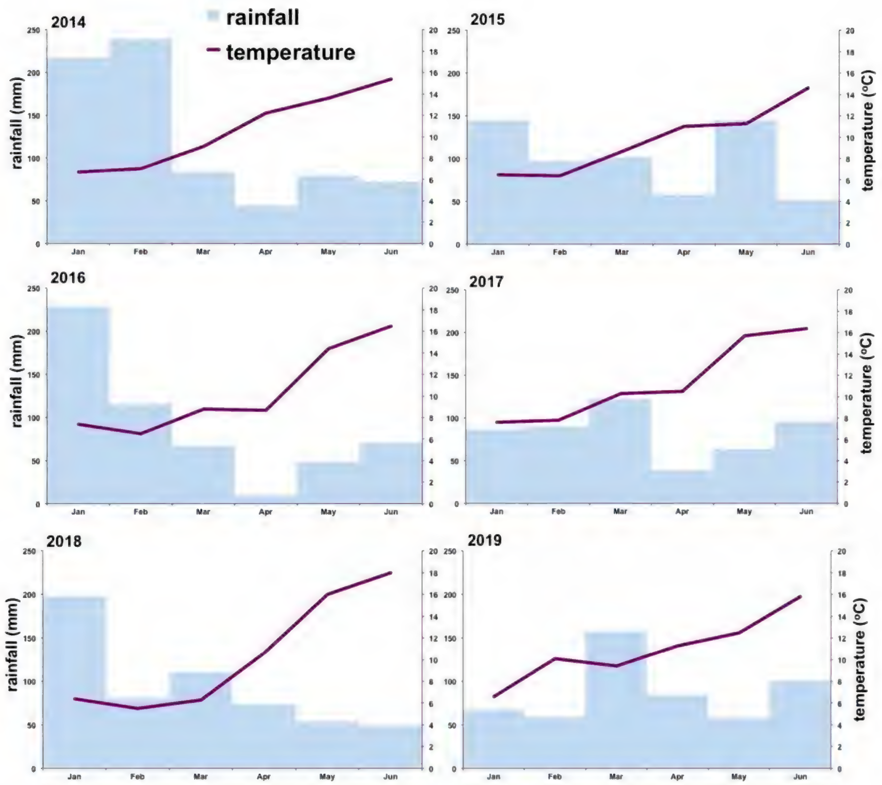

Fig. 2. Monthly rainfall and air temperature for January to June 2014-2019, from Ballypatrick Forest, Northern Ireland (Met Office, 2020). This site is the nearest Met Office meteorological station to Bennane Head, South Ayrshire, for which historic data are readily available, being *ca*. 50 km distant across the Irish Sea.

REFERENCES

Allan, B. & Woods, P. (1993). *Wild Orchids of Scotland*. (Edited by Gregory, N.M. & Bates, M.) HMSO, Edinburgh.

Anon. (2017). Bee orchids are discovered for the first time growing in Berwickshire. *The Berwickshire News*, 19th July 2017. https://www.berwickshirenews.co.uk/news/bee-orchids-are-discovered-first-time-growing-berwickshire-845280

Botanical Society of Britain and Ireland (BSBI) (2020). https://bsbi.org Accessed 15th June 2020.

Harrap, A. & Harrap, S. (2009). *Orchids of Britain and Ireland: a Field and Site Guide*. (2nd edition). A. & C. Black, London.

Laney, B. & Stanley, P. (2004a). *Ophrys apifera* (bee orchid) in Ayrshire (VC75). *Journal of the Hardy Orchid Society* 32, 43. https://www.hardyorchidsociety.org.uk/HOS%201012/jhos.html

Laney, B., & Stanley, P. (2004b). Bee orchid (*Ophrys apifera*) in Ayrshire (V.C. 75). *Botanical Society of Britain and Ireland News* 95, 30. http://archive.bsbi.org.uk/BSBINews95.pdf

Met Office (2020). https://www.metoffice.gov.uk/research/climate/maps-and-data/historic-station-data Accessed 15th June 2020.

National Biodiversity Network (NBN) Atlas (2020). http://www.nbnatlas.org Accessed 15th June 2020.

Registers of Scotland (2020). https://www.ros.gov.uk/our-registers/register-of-sites-of-special-scientific-interest Accessed 15th June 2020.

BOOK REVIEWS

Life Cycles of British & Irish Butterflies

Peter Eeles
Pisces Publications, 2019. 394 pages, hardback with colour photographs and maps. ISBN 978-1-874357-88-9.
£35.00.

Most readers will skip the Acknowledgements section of a book, but in this case it is revealing. The author thanks his family for putting up with him "as I went about creating my life's work". This is no hyperbole, but an apt description of a beautiful and comprehensive book devoted to the 59 species that currently make up the U.K. resident breeding list of butterflies.

The entry for each of the 59 species follows an identical format, and those for two very Scottish butterflies - the mountain ringlet (*Erebia epiphron*) and the chequered skipper (*Carterocephalus palaemon*) - can serve as examples. The entry for the mountain ringlet is six pages long. The title page is a pictorial summary of the four stages of the species (adult-egg-larva-chrysalis) with a photo of each, enclosing a picture of typical habitat. At the bottom of the page is a calendar showing the months in which each stage can be found. There are five pictures of the adult butterfly (including the Scottish and English subspecies *scotica* and *mnemon*). Next are sections on distribution (with a map), habitat (two photos) and status. Then comes the life cycle itself, with three photos of the egg (from newly-laid to pre-emergent), seven photos of larvae covering all six instars, and one photo of the pupa. The whole entry is supported by copious text. That for the chequered skipper runs to a full ten pages with seven photos of the adult, seven of habitat, four of eggs, 18 of larvae and five of pupae. No other book I know of gives coverage to this breadth and depth.

Is it perfect? Perhaps not quite. Two authorial decisions must have been made early on. First, the book has no truck with regular migrants that might become breeding species, e.g. large tortoiseshell (*Nymphalis polychloros*) or long-tailed blue (*Lampides boeticus*), nor with species that have "left the building" but might be persuaded to return, e.g. large copper (*Lycaena dispar*) or black-veined white (*Aporia crataegi*). Second, there is an issue around citations, since many referred to in the text do not appear in the Bibliography. Eeles (who is the founder of *U.K. Butterflies* and *Dispar* websites) has chosen to limit the one-page Bibliography to books only and has put journal references onto a dedicated website. However, since the site also includes new information as it comes in, one could view this as a bonus.

This is a quite outstanding book. The treatment is lavish and the text is both scholarly and readable. It can be recommended unreservedly to any reader with an interest in British butterflies.

Tony Payne

The Vegetative Key to the British Flora (2nd Edition)

John Poland & Eric Clement
Botanical Society of Britain and Ireland, 2020. 556 pages, paperback with colour plates and black & white line drawings. ISBN 978-0-956014-42-9.
£25.00.

I was given the GNHS copy of this book to review just before lockdown in March, 2020. Consequently, I have had ample time to put it to the test. This book truly does exactly what it says on the back cover, the first paragraph of which states "This greatly revised and updated edition to the *Vegetative Key to the British Flora* offers a striking new approach to the identification of nearly 3,000 wildflowers, grasses, sedges, trees, shrubs, ferns and fern allies to be found native, naturalised or casual in the British Isles." It is an amazing achievement.

The first edition was published in 2009. The second edition has many improvements thanks to the authors, John Poland and Eric Clement, who encouraged, accepted and implemented suggestions made by the many enthusiastic users of their first edition, particularly those, like the authors, associated with the Botanical Society of Britain and Ireland. These improvements include rewritten keys, new characteristics, and new species, as well as phenological information.

The majority of books for identifying vascular plants concentrate on characteristics of the flower and fruit, but these features are relatively short-lived compared with the vegetative state of the plant itself. This is a particular problem when detailed surveys are being carried out over time, or when sites are hard to access during the flowering season. There is also the simple satisfaction of being able to identify the non-flowering plant. Many seasoned botanists will be able to recognise a wide range of plants from vegetative characteristics, but the development and refinement of keys that permit identification and verification from such features is an extraordinary achievement. The keys are innovative and much effort has been made to keep them as user-friendly as possible to allow speedy identification. I think they do take a bit of getting used to, but the accompanying glossary and excellent line drawings all help, as do the equally excellent colour plates illustrating leaf morphology and other anatomical features. I have personally used the keys and the descriptions at species level for *Rumex* and *Valerianella* identification and found them able to resolve tricky issues. Seeds and fruits will feature if required. It should be noted too that this latest edition includes up-to-date taxonomic nomenclature (following C.A. Stace: *New Flora of the British Isles*, 4th edition, 2019), invaluable for professional records.

There can be little doubt that this new volume is an essential for the professional botanist, ecologist etc., and a huge asset to all others wishing to improve their ability to identify vascular plants or satisfy their curiosity. It backs up and adds to all other means of identification. It is a developmental aid which really improves observational skills. I still find it quite mind-blowing what the authors have achieved. So, my conclusion: you will not regret getting yourself a copy of this extraordinary piece of work.

Alison Moss

The Essential Guide to Rockpooling

Julie Hatcher & Steve Trewhella
Wild Nature Press Ltd., 2019. 304 pages, paperback with colour photographs, illustrations and line drawings. ISBN 978-0-9955673-1-3.
£16.99.

This guide is a compendium of everything you want to know about the fauna and flora inhabiting our seashore rockpools. The introductory section, at 20 pages, is relatively short, but provides a résumé of the rockpool habitat and its ecology along with simple explanations of tides, shore zonation and threats to rockpool life. Useful guidance is provided on how to explore rockpools, including emphasis on the seashore code, as well as what kit to bring, how to keep safe, and recording your findings. Photographs of unusual hexagonal rockpools at the Giant's Causeway and dinosaur footprint rockpools in Skye add an unexpected twist.

The bulk of the book comprises sections on seaweeds, lichens, sponges, bryozoans, cnidarians, worms, crustaceans, molluscs, echinoderms, sea-squirts, fish, birds and mammals. If you are not familiar with all these groups, a brief outline of their attributes is presented in each section, with further details for many subgroups within the sections. The plant and animal groups are arranged in evolutionary order, as is the norm, and interspersed with these is a series of mini-guides on associated activities: extracting fauna from seaweeds, pressing seaweeds, photography, crabbing, night-time rockpooling, pootering, goggling, bioblitzing, and beach cleaning. All of these invite the reader to delve deeper into the rockpool world.

The guide is packed full of beautiful colour photographs, mostly produced by the authors, a husband and wife team based in Dorset. Additional images have been provided by David Fenwick, a renowned natural history photographer, also from south-west England. Not surprisingly, there may be a slight bias towards south-west species but this provides an opportunity to highlight interesting, and rare, species including new arrivals to British shores such as the spectacular anemone shrimp (*Periclimenes sagittifer*). There are so many good photos and fascinating creatures it is hard to pick favourites. Many of the photos have been taken in the field but quite a few are clearly studio photos using dark field imaging of live animals against a black background. This technique accentuates the colours and patterns of many rockpool inhabitants and elevates the photography into an art form.

The authors use common names, where available, for the seaweeds and animals, accompanied by proper scientific names. Some of the common names used may be quite unfamiliar but, nowadays, it is considered good conservation practice to introduce common names to help highlight our varied marine fauna and flora and bridge the gap between amateur and professional marine biologists. One little hermit crab species (*Clibanarius erythropus*), recently re-discovered in Cornwall, was given a brand new common name - the St. Piran's crab - in a competition in 2016. Annoyingly the crab has lost its apostrophe in the figure title and confusingly is also labelled red-legged soldier (crab?) in an accompanying figure. A small price to pay for this beautiful debutante crustacean.

These nit-picking gripes aside, this is an excellent volume for the inquisitive seashore investigator with around 400 seashore species illustrated and described. It is aimed at the enthusiastic amateur and avoids identification keys and the few technical terms that are used are explained in a short glossary. It is not an exhaustive inventory of seashore species and the reader is directed to standard guides in the reference section for those that want to move their identification skills up a level. This book is a companion to *The Essential Guide to Beachcombing and the Strandline* (by S. Trewhella & J. Hatcher, Wild Nature Press, 2015) which has a similar format and together they form a first class armoury for those who love to explore our shores and learn about their wildlife.

Myles O'Reilly

Atlas of Britain & Ireland's Larger Moths

Zoe Randle (and ten other authors)
Pisces Publications, 2019. 492 pages, hardback with colour photographs, maps and line diagrams. ISBN 978-1-874357-82-7.
£38.50

I have been recording moths on a regular basis since 2002. In that time two books in particular have encouraged my interest: *Field guide to the Moths of Great Britain and Ireland* (by Paul Waring & Martin Townsend, Bloomsbury Publishing, 2009) and *Field Guide to the Micro Moths of Great Britain and Ireland* (by Phil Sterling & Mark Parsons, Bloomsbury Publishing, 2012). Now there is a third publication which I expect to use on a regular basis. *The Atlas of Britain & Ireland's Larger Moths* has had a long development. It began in earnest with the Moths Count Project in 2006 and the establishment of the National Moth Recording Scheme by Butterfly Conservation in 2007 (with funding from a wide group of organisations). Moths Ireland had been founded in 2005. The two organisations have combined to produce the first atlas of larger (or macro) moths of Britain and Ireland to include distribution maps for all species.

A total of 25,642,265 records has been used as the basis for the atlas, dating from 1741 (a Kentish glory) up to the end of 2016, covering 97% of all the 10 km squares. Following submission, all the British records have been checked and verified by a dedicated team of County

recorders. The Irish records were checked by two verification committees.

The atlas has a forward by Sir David Attenborough, followed by acknowledgements to the individuals and organisations involved. There were many thousands of people who submitted records, so only the "key players" are named individually. The names of just the County Moth Recorders and the Irish verification committees take up a complete page, which gives an indication of the amount of work involved in this project.

An introduction explains how the atlas project came to happen. Then there is a section on recording, analysis and an explanation of the layout of the entries for each species. There is then an analysis of the results, followed by a discussion on why the distribution and abundance some species have changed, and finally how the analysis of all the records can be used to help moth conservation.

For each species there is a small (but high quality) image of the adult moth and a distribution map with three date categories: pre-1970; 1970-1999; and 2000 onwards (which means 2000-2016). For each of these date periods there are numbers given for the number of recorded squares for Britain (including the Channel Islands and the Isle of man) and separately for Ireland (Republic of Ireland and Northern Ireland). There are then percentages given for the change in distribution for two periods (1970-2016 and 2000-2016) and for abundance for 1970-2016. A short paragraph then states if the species is a resident or migrant and gives a general description of its distribution and habitats and whether it is increasing, declining or otherwise. Finally there is a bar chart showing the flight period(s) of the moth, showing two periods (1970-2016 and 2000-2016). This is a very good visual way of showing how some species are now emerging earlier or later, or flying later in the year than in the past. There is a straightforward index and bibliography.

Over 400 individuals and organisations have sponsored one or more species, and many well known names can be seen, including a dedication to the late John Knowler (a GNHS member and President), who did much to encourage interest in moths in the Glasgow area.

Of the 893 species included, 867 have an account with an associated dot map. For the moths that have abundance data available, 25% have declined since 1970. But not all are doing badly. The maps show several species that are new colonists from Europe. The number of species showing an expansion of their distribution (though not necessarily increased abundance) is greater than the number showing a decline.

The maps clearly show how species distributions have changed over time. A good example is the mallow (*Larentia clavaria*). It has shown an obvious decline in the north of its range and is shown as now being extinct in Scotland. Of course any atlas is bound to become out of date as new discoveries are made. The mallow was refound in East Lothian in 2020. No doubt a future edition will show this and other such changes.

By contrast, the spruce carpet (*Thera britannica*) has shown a very large increase in both distribution and abundance since 1970 and is now found as far north as Orkney.

With any atlas, it is always good to look up a species when you find something new. I have already used it several times to check the distribution of moths I have trapped for the first time in my garden. It gives an excellent summary of the current status of each species, based on the best data available. For example, I had white-pinion spotted (*Lomographa bimaculata*) in my trap for the first time in 2019. The atlas shows that it only reached Scotland in 1997, but has already reached just north of the Central Belt. It is one of several species that are new arrivals north of the border.

If you want to know the current distribution and status of our larger moths, I would thoroughly recommend this atlas to you.

Richard Sutcliffe

Exploring Britain's Hidden World. A Natural History of Seabed Habitats

Keith Hiscock

Wild Nature Press, 2018. 272 pages, hardback with colour photographs, illustrations and diagrams. ISBN 978-0-99-55673-4-4.
£24.99.

This is a seminal work, the sort that only appears once in a life-time and is also a description of a life-time's work by eminent marine biologist Keith Hiscock, observing the undersea realm around our coasts. It describes his 50 years of research and survey work on Britain's seabed habitats and draws upon knowledge of British marine life gathered over the last 200 years. This is a hefty tome with around 250 large format pages, richly illustrated throughout with high quality colour photographs and beautifully produced diagrams explaining the underwater world and its inhabitants.

The book begins with an outline of historical marine biological studies around Britain going back as far as the 1800s and includes the establishment of the marine stations at St. Andrews, Plymouth, Millport and Port Erin. The early scientists studied the seabed remotely using dredges and grabs and the seabed fauna of the British Isles became the best known in the world with early descriptions and classifications of seabed communities being developed. However, huge knowledge gaps remained. The early use of diving gear and underwater photography for seabed surveys is described along with the developments over the last 50 years with SCUBA diving surveys and improving underwater photo and video technology. The various methods utilised for seabed sampling and surveying are depicted and the concepts of marine biotopes and their mapping introduced.

The author was deeply involved in the Marine Conservation Review of Great Britain (MNCR) which commenced in the late 1980s and, over the next decade, went on to develop the marine biotope classification system which underpins the understanding of our marine communities. Although the biotope classification system is described at some length, its use - and the use of technical terms in general - is kept to a minimum throughout; a handy glossary is provided, so that this volume is accessible to a general natural historian.

The following section provides an account of all the factors that shape the seabed environment, including the physical geography and the currents, tides, temperature, wave exposure, salinity, depth and light penetration – a lesson on Britain's unique oceanography.

The main section of the book is just under 150 pages long and deals with the various seabed habitats – sediments, rocky areas, sea lochs, rias and voes, tidal races, estuaries, and saline lagoons. Each is discussed and described with photographs of key species and wonderful three-dimensional dioramas depicting the myriad of inhabitants both visible on the surface and burrowing beneath. Scotland features heavily, with its hugely varied coastline harbouring more than its fair share of habitats. We have all the sea lochs and voes and most of the saline lagoons, not to mention numerous reefs, and tide swept channels. Of particular interest are keystone species which themselves form unique habitats – including seagrass beds, kelp forests, maerl beds, horse mussel reefs, flame shell reefs (all fairly abundant in Scottish waters) and the rare and spectacular serpulid tube-worm reefs found only in Loch Creran.

The next section looks at changes in these seabed habitats. These include well understood seasonal changes as well as longer term decadal fluctuations whose causes may be related to larger scale oceanographic oscillations. The effects of diseases (e.g. in seagrasses and pink sea fans) are discussed along with the impact of non-native invasive species such as slipper limpets (*Crepidula fornicata*), carpet sea squirts (*Didemnum vexillum*) and wireweed (*Sargassum muticum*). As this work focuses on natural marine seabed communities, there is only minimal mention of the effects of human activities. The effects of climate change and seawater warming highlight potentially receding northern species, and those apparently advancing from the south; the latter include new arrivals to British waters, such as the variable blenny (*Parablennius pilicornis*) or the anemone shrimp (*Periclimenes sagittifer*).

Finally, an overview is presented on past conservation efforts and those taking place now to help protect the seabed environment, together with the impact of new technologies in helping us to survey seabed communities and collate, analyse, interpret and display information on Britain's marine life.

This is a delightful book to browse through. It showcases our seabed communities, both the glamorous and colourful epifauna, and the more clandestine burrowing creatures. It is a boon to natural historians, peppered with anecdotes on little known gems on our marine fauna, such as the mysterious red bandfish (*Cepola macrophthalma*), which hides in seabed burrows, or the extremely rare fan mussel (*Atrina fragilis*), found off Canna, and up to 40 cm long! Anyone with an interest in British marine biology should have this work on their bookshelf.

Myles O'Reilly

How Wildlife Photography Became Art: 55 Years of Wildlife Photographer of the Year

Rosamund Kidman Cox
Natural History Museum, London, 2020. 288 pages, hardback with many colour photographs. ISBN 9780565095130.
£35.00

This is a large and heavy volume containing, as you might expect, many excellent photographs, produced to celebrate 55 years of the Wildlife Photographer of the Year competition.

The book begins with a brief coverage of the history of photography from the mid-19th century, including many famous names such as Cherry Kearton and Eric Hosking.

After an account of early feats, including trip wires, the use of flash, and Herbert Ponting's photography in Antarctica with Captain Scott, the book celebrates the rise of the competition, showing David Attenborough presenting the first Wildlife Photographer of the Year to C.V.R. Dowdeswell, and describing techniques of fieldcraft and technical developments through the decades. In the first competition there were 361 entries. During the 1980s, the competition widened in scope, with 11 categories including underwater photography. Today there are over 45,000 entries.

Each chapter pursues a theme, the first being "The art of seeing" in which the photographer chooses the composition through planning, knowledge and the application of technique to produce an image which lasts - a winning picture which is always original. A brief summary of the other chapters now follows.

"Down to Eye Level" deals with eye-level perspective, which creates a dramatic effect. Frans Lanting was an influential proponent of this approach.

"A Sense of Place" covers animals in their environment, both setting the scene and conveying a message.

"And Then There was Light" describes how special light creates a sense of mood and place, emphasising the golden hour around sunrise and sunset, and examining the role of soft diffused light and even darkness.

"The Moment". A chase, a fight or a kill: catching the decisive moment requires being in the right place at the right time, and requires skill and experience. However, when dealing with wildlife, success is never guaranteed.

"Wild Spaces" covers places from the high Arctic via the Lairig Ghru and Morecambe Bay to Patagonia and the southern oceans, and shows the importance of careful planning and intimate knowledge of the area and of photographic techniques including the use of wide-angle lenses to show foreground vegetation again a dramatic backdrop, of panoramic or underwater photography (or in one case both!), or of icy scenes which with climate change might not be there by 2030.

"Natural Design" focuses on simplicity, emphasising natural patterns which bring to the eye of the viewer an intrinsic natural appeal, including both animals and the landscape. Amongst contributory factors are mist, snow, low winter sun and reflections from still waters, and amongst techniques allowed in the competition was focus stacking to obtain a great depth of field.

"The White Canvas" shows photos which use snow, ice or a pale sky as a canvas for carefully executed and often seemingly simple compositions.

"Faster and Faster" traces developments in photographic techniques over the years, from flash powder, glass plates and heavy tripods to modern high ISO cameras, motor drives, autofocus and through the lens metering, which together make it possible to shoot sharp high-speed action sequences. The results are illustrated by dramatic shots of birds in flight.

"The Portrait and the Pose". A compelling portrait is one which causes you to pause and think about the animal, its character and its life. Not only is this achieved with stunning individual animals as diverse as sea horses, walrus and gannets, but carefully executed group shots too, such as elephants and monkeys.

"Remote Design" covers the development of taking pictures remotely using heavy and cumbersome techniques such plate cameras with trip wires and remote flash to modern infrared trip beams and wireless flash. Much thought is required to achieve the best pose, illustrated by a variety of animals.

"The Tiny Things in Life" features, as you might expect, macro photographs of insects, but also spiders and even a sea squirt!

"And Then There Was Night" illustrates early flash photography, and also modern digital images taken in the limited natural evening or night light, using high ISO settings. Amongst the most interesting photos are where the natural foreground is combined with the night sky showing star trails, and an image of a killer whale blowing taken by a number of flashes.

"Telling a Story" through the means of a single picture invites a challenge, as action so often happens out of sight - underground, underwater, at night, high up or at microscopic level.
This is illustrated by a snake swallowing tree frog eggs, which slide out of its mouth, hatch spontaneously and drop into the water below, the actual moment captured after weeks of preparation, and by a humming bird pollinating an orchid after two weeks of waiting and six flashes set up.

"Back to Black and White" was a category of the competition started after 12 years of accepting only colour entries, for which there had been a strong demand for magazine articles. From a family of kingfishers, through a night time cheetah, to a murmuration of starlings, the medium of black and white emphasises pattern instead of colour.

"Aerial Exposure". To show the sheer scale of things and highlight patterns in the landscape or of animal movement, there is little to beat aerial photography. Examples include the desolate eroded landscape of central Madagascar, denuded of vegetation and with soil washing into its rivers - a scene that triggered foreign aid to the country; a Scottish raised bog being stripped bare for horticultural peat; and a pod of narwhals in a lead (narrow crack) in sea ice, photographed after weeks of organisation, including the purchase of a float plane. Where it is not practical to hire a plane, the more recent development of drones has led to new creative possibilities, one example in the book being an aerial photograph of seals on an iceberg.

"The Underwater Revolution" charts the development of underwater photography through the invention of new techniques using housings and aqualungs, and pioneering the art of the split field technique, where half the shot is underwater and half above. Underwater images in this chapter include beluga whales, emperor penguins and sharks bursting out of a bait ball with fish in their mouths, and magnificent sea pens. There is great potential for new underwater images from this relatively unexplored environment.

"The Passion of Youth". From 1981, prizes were offered for photographers under 17. This coincided with increasing availability of more affordable equipment and the boom in TV wildlife programmes, and today the competition has fulfilled one of its original aims of inspiring a new generation of photographic artists. An inspiring collection of photos by young photographers is shown, many of whom are now household names in Britain.

"The Final Message" presents pictures which make you stop and think - the last of the golden toads in Costa Rica before they succumbed to chytrid disease, the head of a gorilla in a frying pan, a loggerhead turtle and a thresher shark caught in a fishing net, men carrying away a bloody tusk from an illegally killed elephant, one of the last Sumatran tigers, a polar bear on thin ice showing the uncertain future for this species, oiled pelicans awaiting cleaning by volunteers, an iconic image of a seahorse

with its tail grasping a cotton bud floating in the ocean, and finally a dead rhino with its horn newly hacked off.

All in all this, is an enthralling book, at once fascinating, uplifting and horrifying, full of beauty, wonder and tragedy.

David Palmar

The Glasgow Naturalist (2021) Volume 27, Part 3, 125-127

OBITUARY

John Mitchell (15th January 1934 - 16th March 2019) Photograph taken in Touch Hills, Stirlingshire, spring 2007, at the location where Schleicher's thread-moss (*Bryum schleicheri* var. *latifolium*) was rediscovered, the only remaining population in the British Isles.

John Mitchell is widely and justifiably recognised as an outstanding all-round naturalist with a broad and deep knowledge of both fauna and flora. He was well known to many members of Glasgow Natural History Society and made a remarkable contribution to the understanding and conservation of the Loch Lomondside area.

John, originally from Peterborough, Cambridgeshire arrived in Glasgow in the early 1960s but his interest in natural history was by then well developed. This interest appears to have blossomed in the 1950s during his two years of National Service, a time when he first encountered the young Derek Ratcliffe, which he amusingly recounts in an article (Mitchell, 2015). His subsequent interactions, over many years, with the soon to be famous naturalist Derek Ratcliffe were to have a profound influence on his future career and interests.

John was born at the family home in Muswell Road, Peterborough on 15th January 1934 and baptised at Orton Waterville Parish Church (St. Mary's). From 1938 to 1944 he attended West Town infant and junior school, and later attended a local grammar school - The Deacon School - where he stayed until he was 16 years old.

John came from a musical family. His father and younger brother both played trumpet whilst his paternal grandfather played euphonium. John was started on piano but switched to trombone when his arms grew long enough to reach the sixth position. During his youth John played with the Salvation Army Junior Band, the Peterborough Junior Orchestra, Northants T.A. Regimental Band, as well as the pit orchestra for the local Gilbert and Sullivan Society and a brass quartet, most of these with his brother Neil.

When it came time to leave school, he was interested in bird-watching, which was his favourite hobby, and music. He attended a meeting with the school careers advisor who recommended he consider a career in pig breeding! His father wanted him to go into banking. Since neither of these appealed to John, he applied to join the army as a musician on boy's service, auditioned with the Royal Signals, and was accepted as a trombonist. He moved up to Catterick Camp, in North Yorkshire, to join the Royal Signals where the next chapter of his life was to begin.

Although John was, in his own words, "a fair trombonist", he was not totally enthusiastic about the obligatory requirement for physical exercise during his role with the Staff Band of the Royal Corps of Signals. He recounts how his attempts at avoidance led him to take refuge in the Education Building, where he noticed an invitation to join a fledgling field club instigated by the Sergeant Education Instructor, one Derek Ratcliffe. John humorously recounts how one of the benefits of forming a club meant that Derek could then get access to an army vehicle and driver to enable excursions! Following visits to many places in the north Yorkshire area, John notes how he and his fellow members were in awe of Derek's breadth and depth of knowledge at the time, an accolade which most of us would now happily impart about John.

As part of his days in the Royal Signals, John was required to train on a second instrument. Because he was over six feet tall, he was told he was to play double bass for his second instrument. Playing the double bass meant that John could earn extra money playing in the officers' mess and also play gigs outwith the confines of the army barracks.

John left the army in the mid-1950s and became a much-in-demand musician, holding down London residencies at venues such as The Dorchester Hotel and The

Piccadilly Club. He would also go to seaside resorts to do a summer season, which was well paid work. He played in North Wales with The Harry Leader Big Band, Birmingham with 'Johnnie Gray and His Band of the Day' and, crucially, a summer season up in The Beech Ballroom, Aberdeen. It was here that John was amazed by the fact that you could drive for half an hour and be completely lost in the countryside. His intention had been to stay in Scotland for this six week summer season. He was to spend the next 60 years in Scotland, only returning to Peterborough for a short holiday each year.

John explored further afield and fell in love with the riches of the Loch Lomond area. He sought out work in the nearest city, which was Glasgow, and joined the 'Dave Mason Big Band' where he held down a residency at The Majestic Ballroom. It was in Glasgow that John met his future wife Sandra. Driving home from his gig in November 1962 he saw a woman being accosted by a drunk on Renfrew Street and stopped his vehicle to rescue her. They eventually married and lived at first in a caravan park in Cardowan near Stepps. After the arrival of their sons - first Andrew then Cameron, they moved to the vicinity of Gartocharn, on the southern edge of Loch Lomond.

It was at this time that John's natural history interest took centre-stage and gradually phased the music out. This change came about due to another chance encounter with Derek Ratcliffe. Reading an article in *Scottish Field* magazine in a Glasgow dentist's waiting room, John learned that Derek, whom he had not seen for ten years, was now in Scotland working for the Nature Conservancy. John and Sandra visited Derek in Edinburgh and not long after they rekindled their mutual interest in field excursions, with trips to the northern Pennines and the Cairngorms, studying respectively the nesting of golden plover (*Pluvialis apricaria*) and dotterel (*Charadrius morinellus*). It was on his trip to Caenlochan that he was introduced to its rich arctic-alpine flora, a passion which he continued to enjoy for many years after.

During his meeting with Derek he found himself agreeing to take on the annual monitoring of peregrines (*Falco peregrinus*) and ravens (*Corvus corax*) in the Loch Lomond and Trossachs area, an endeavour which John noted came "to occupy all of my spare time every April to June for the next 25 years". The connection to the Loch Lomond area would become the defining feature of John's prowess as a natural historian, as he became the authority on the local history of Loch Lomondside. This knowledge grew quickly during his tenure with the then Nature Conservancy as the reserve warden for the Loch Lomond National Nature Reserve (NNR), a position he held for 27 years before retiring in 1994. He was also involved with the setting up of the Loch Lomond and the Trossachs National Park, Scotland's first, established in 2002.

As his knowledge and experience grew, John was invited to prepare a course of lectures on Loch Lomondside for the University of Glasgow's Department of Further Education. The need for an affordable and comprehensive resource for students resulted in John and a group of fellow tutors producing a booklet in 1974 entitled *A Natural History of Loch Lomond*.

A search of the Botanical Society of Britain and Ireland (BSBI) database reveals John contributed some 3,500 botanical records, mostly of interesting plants found at Loch Lomondside but also many wider Scottish mountain species. His records span over 40 years from early days with GNHS members such as Robert Mackechnie and many with his good friend and close collaborator the late Allan Stirling; more recently he made excursions with Edna Stewart and Pam Murdoch. Jim Dickson enjoyed excursions with John during the 1970s to 1990s. He considers John was an "outstanding natural historian" and recalls that his "pleasant company and great, broad knowledge of natural history was of no little benefit to me".

John was well respected by former colleagues during his time as reserve warden, including fellow warden John Cameron and bryologist Nick Hodgetts who worked for a short time as an area officer in Balloch. Nick enjoyed many excursions with John, considering him great company and "one of the last of the old school warden-naturalist breed". They visited the national rarity Schleicher's thread-moss (*Bryum schleicheri* var. *latifolium*), which John, and former GNHS members Gerry Rodway and Allan Stirling, rediscovered in 1968 in the Touch Hills. John also found the diminutive rarity dwarf bladder-moss (*Physcomitrium sphaericum*) at Wards Pond on the reserve in 1980. After Nick got married in 1987 he recalls John's tongue-in-cheek words of advice "When you're married, the most difficult step of any botanical journey is the one that takes you out of the front door"!

John's knowledge of the local flora extended to details of populations and ecology, based on many years of observations. He could combine his visits to study birds with seasonal observations of plant populations; perhaps it is not surprising that many of his interesting local botanical finds were of specialists of water margins such as the eight-stamened waterwort (*Elatine hydropiper*), pillwort (*Pilularia globulifera*) and mudwort (*Limosella aquatica*). I encountered John on several occasions when studying populations of Red Data Book species on Loch Lomondside. John was the first, and most valuable, stop for information and localities of the eight-stamened waterwort, Scottish dock (*Rumex aquaticus*) and elongated sedge (*Carex elongata*).

Norman Tait fondly remembers John leading local botanical field trips around Loch Lomondside where he introduced him to many new and interesting plants. Norman also highlights the range and quality of the many slides and prints which he helped to process for John's prodigious output on local history and natural history topics.

Over a period of some 50 years John was a prolific writer of articles and notes on a remarkable range of subjects and topics. His long bibliography includes papers on many aspects of the flora (including cryptogams), ornithology, mammals, fish and diverse invertebrate groups. However, his knowledge also extended to authoritative accounts on local geology, folklore, landscape and vegetation history, plus biographies of local naturalists and historical articles on Loch Lomondside and the Drymen area, where he lived in retirement with Sandra. John was the first chairman of the newly formed Drymen and District Local History Society in 1981.

David Clugston has noted that "John was a gifted writer who had the ability to engage the reader by making his chosen subject really interesting and not too technical". This is perhaps most ably manifest in his contribution to the Collins 'New Naturalist' series - *Loch Lomondside* (Mitchell, 2001), about which Jim Dickson writes "In my opinion it is one of the very best, a very fine memorial to John". John himself has written that without the constant encouragement and support of Derek Ratcliffe, the book may never have seen the light of day.

John was awarded an Honorary MA by the University of Stirling (1991) and the Fellowship of the Royal Zoological Society of Scotland (1994). As a very long-standing member of GNHS he was recently awarded Honorary Membership for his outstanding contribution in writing around 50 papers and notes for *The Glasgow Naturalist.*

David Clugston has written that "John was a thoroughly nice guy and very good company. Although tending to shun the limelight he was always happy to pass on the wealth of both his natural history knowledge and increasingly on the history of the Drymen area".

John will be long associated with Loch Lomondside, and his memory will live long thanks to his extensive written legacy. He will be sadly missed but he will be fondly remembered by many members as intelligent, enthusiastic, amusing and deeply knowledgeable.

ACKNOWLEDGEMENTS
I am grateful to David Clugston for granting permission to reproduce extracts from his note in the GNHS Newsletter for April 2019 and to Jim Dickson for providing some thoughts and appreciation of his interactions with John over the years. I am particularly indebted to John's family, notably his brother Neil and son Andrew, for supplying extensive detailed information on John's early years up to his arrival in the Glasgow area, much of which is reproduced above.

REFERENCES
Mitchell, J. (2001). *Loch Lomondside*. HarperCollins, London.
Mitchell, J. (2015). National Service and beyond. In: Thompson, D.B.A., Birks, H.H. & Birks, H.J.B. (Editors), *Nature's Conscience: the Life and Legacy of Derek Ratcliffe*, pp. 21-25. Langford Press, Kings Lynn.

Keith Watson

The Glasgow Naturalist (2021) Volume 27, Part 3, 128-130

PhotoSCENE 2019-20

PhotoSCENE Natural History Photographic Competition

The annual PhotoSCENE competition is sponsored by Glasgow Natural History Society and the University of Glasgow Institute of Biodiversity, Animal Health and Comparative Medicine. It aims to promote interest in Natural History and the work of SCENE (Scottish Centre for Ecology and the Natural Environment, the University's field station at Rowardennan, Loch Lomond), promote linkage between the Institute and the Society, and provide pictures for publicity. All entrants are thanked for making the effort to enter the competition. Prizes totalling £800 per year have been awarded at the Society's photographic nights. Since the first competition in 2011, and together with talks from members, the competition has provided us with an interesting photographic evening each February. This year there were 76 entries from 17 people.

D.C. Palmar

Overall Winner:

Norman Still - A pair of longhorn beetles (*Pachytodes cerambyciformis*) mating on a burnet rose (*Rosa pimpinellifolia*), Balgownie Woods, Fife, Scotland, 22nd June 2020.

First Prize Winners:
These include the photographs by Jonathan Archer and Chris McInerny that feature on the front and back covers respectively. Information on these photographs is provided on the inside front cover. The other first prize winners are shown below and on the following pages.

Kirsty Kennedy-Wylie - Red deer (*Cervus elaphus*), Bridge Orchy, Argyll, Scotland, 20th October 2019.

Sarah Longrigg - Bird-cherry ermine moth (*Yponomeuta evonymella*) caterpillars preparing to pupate on foxglove (*Digitalis purpurea*), Mugdock Wood, Stirlingshire, Scotland, 8th June 2020.

Robyn Haggard - Dark green fritillary (*Speyeria aglaja*), Ben Venue, Stirlingsire, Scotland, 18th July 2020.

Andy Wilson - Leaf veins, common alder (*Alnus glutinosa*), Cambuslang, South Lanarkshire, Scotland, 30th July 2020.

The Glasgow Naturalist (2021) Volume 27, Part 3, 131-132

PROCEEDINGS 2019

The lecturer's name and the title of the lecture are given for each meeting, as is the location, which was within the University of Glasgow unless stated otherwise. Most of the meetings were reasonably well attended with the joint lectures being very well attended.

January 8th
Lecture 1: "Re-homing Ratty - balancing the needs of urban water vole populations with redevelopment in Glasgow" from Robyn Stewart. Lecture 2: "Predicting the future - from house sparrow behaviour to population change" from Ross Macleod. Boyd Orr Building.

February 12th
Photographic Night. Members' slides or digital slide shows, plus results of the PhotoSCENE competition. Boyd Orr Building.

February 14th
Lecture: "The Heath Robinson world of the Triassic" from Nick Fraser, jointly with the Geological Society of Glasgow. Gregory Building.

March 7th
Expeditions Report Back, jointly with the University of Glasgow Expeditions Society. (Most expeditions are supported by the BLB Bequest.) Graham Kerr Building.

March 12th
Annual General Meeting, followed by Lecture: "Freshwater invertebrates in Scotland: their importance and conservation" from Craig Macadam. Boyd Orr Building.

April 9th
Lecture 1: "Insights and challenges of expeditionary life - engaging young people in science in extreme environments" from Lauren Lochrie. Lecture 2: "Biodiversity monitoring on the University of Glasgow campuses" from Stewart White and colleagues. Boyd Orr Building.

May 14th
Lecture: "John Russell Malloch and Alexander Cuthbertson - two Glasgow naturalists who made a global impact on dipterology, the study of flies" from Geoff Hancock, jointly with Paisley Natural History Society and Hamilton Natural History Society. Boyd Orr Building.

June 11th
Summer Social held at Hilton Grosvenor, preceded by a visit to the Orchid Houses at Glasgow Botanic Gardens.

September 17th
Lecture: "Returning a native: beaver restoration to Britain" from Roisin Campbell-Palmer. Boyd Orr Building.

October 8th
Lecture 1: "The Clyde Marine Region − beneath the waves" from Rebecca Crawford. Lecture 2: "A review of biological recording infrastructure in Scotland − progress report" from Rachel Tierney. Boyd Orr Building.

November 12th
Lecture 1: "Plants, mycorrhiza and evolution" from Jim Downie. Lecture 2: "Wintering jack snipe in Glasgow" from Iain Livingstone. Boyd Orr Building.

November 14th
Lecture: "A quest for trees" from Tom Christian, jointly with Friends of Glasgow Botanic Gardens and the Glasgow Treelovers Society. Bower Building.

December 10th
Christmas buffet dinner followed by Lecture: "Amber − tears of the gods" from Neil Clark. Graham Kerr Building.

Excursions
12 day excursions, two joint excursions with the Clyde and Argyll Fungus Group and one weekend excursion were held throughout the year.

Officers and Council elected at the 2019 AGM

President
Chris McInerny

Vice Presidents
Barbara Mable
Roger Downie

General Secretary
Mary Child

Assistant Secretary
Lyn Dunachie

Treasurer
Susan Futter

Winter Syllabus
Roger Downie

Excursions
Alison Moss

Membership Secretary
Richard Weddle

Librarian
Janet Palmar

***The Glasgow Naturalist* Editor**
Iain Wilkie

***The Glasgow Naturalist* Assistant Editor**
Chris McInerny

***The Glasgow Naturalist* Assistant Editor**
Ruth Maclachlan

Newsletter Editor
David Palmar

Section Convenors
Richard Weddle: Bio-recording
Alison Moss: Botany
Ann Ainsworth: Geology
Norman Storie: Ornithology
David Palmar: Photography
Myles O'Reilly: Zoology

Councillors
Bob Gray
Erik Paterson
Laura Allen
Tony Payne
Kirsty Kennedy-Wylie

BLB Executive
Chair: Barbara Mable
Secretary: Mary Child
Treasurer: Susan Futter
Scientific Advisor: Tony Payne
Technical advisor: Richard Weddle
Financial Advisor: Bob Gray

The Glasgow Naturalist

Information for Contributors

1. *The Glasgow Naturalist* publishes full papers, short notes and book reviews. All articles are peer reviewed by a minimum of two reviewers. The subject matter of papers and short notes should concern the natural history of Scotland in all its aspects, including historical treatments of natural historians. Details of the journal can be found at: www.gnhs.org.uk/publications.html

2. Full papers should not normally exceed 20 printed pages. They should be headed by the title and author, postal and email addresses. Any references cited should be listed in alphabetical order under the heading References. All papers must start with a short abstract of up to 200 words, which should summarise the work. The text should normally be divided into sections with sub-headings such as Introduction, Methods, Results, Discussion, Acknowledgements and References.

3. Short notes should not normally exceed two printed pages. They should be headed by the title and author's name, postal and email address. Any references cited should be listed in alphabetical order under the heading References. There should be no other sub-headings. Any acknowledgements should be given as a sentence before the references. Short notes may cover, for example, new locations for a species, rediscoveries of old records, ringed birds recovered, occurrences known to be rare or unusual, interesting localities not usually visited by naturalists, and preliminary observations designed to stimulate more general interest.

4. References should be given in full according to the following style:

Pennie, I.D. (1951). Distribution of capercaillie in Scotland. *Scottish Naturalist* 63, 4-17.

O'Reilly, M., Nowacki, S. & Gerrie, E. (2018). New records of the white-banded grapple-worm. *The Glasgow Naturalist* 26(4), 96-97.

Wheeler, A. (1975). *Fishes of the World*. Ferndale Editions, London.

Smith, C.W., Aptroot, A., Coppins, B.J., Fletcher, A., Gilbert, O.L., James, P.W. & Wolseley, P.A. (2009). *The Lichens of Great Britain and Ireland*. (2nd edition). The British Lichen Society, London.

Grist, N.R. & Bell, E.J. (1996). Enteroviruses. In: Weatherall, D.J. (Editor). *Oxford Textbook of Medicine*, pp. 381-390. Oxford University Press, Oxford.

References with more than six authors: name the first six authors, then add "*et al.*"

5. References should be cited in the text as follows:

Single author: Pennie (1915)… (Pennie, 1915). Two authors: Grist & Bell (1996)… (Grist & Bell, 1996). More than two authors: Smith *et al.* (2009)… (Smith *et al.*, 2009). Multiple citations: (Pennie, 1915; Grist & Bell, 1996). Same author(s), publications in different years: (MacGillivray, 1840, 1855).

6. An organism's genus and species names should be given in italics when first mentioned. Thereafter only the common name is required. Please use lower case initial letters for all common names, e.g. wood avens, blackbird, unless the common name includes a normally capitalised proper name, e.g. Kemp's ridley turtle. The nomenclature of vascular plants should follow Stace, C.A. (2010). *The New Flora of the British Isles*. (3rd edition). Cambridge University Press, Cambridge. Normal rules of zoological nomenclature apply. When stating distribution, it may be appropriate to give information by vice-county.

7. All papers, including electronic versions, must be prepared on A4, double spaced throughout, with margins of 25 mm, with 12 point Times New Roman font. Tables and the legends to figures should be typed on separate pages at the end of the manuscript.

8. Tables are numbered in arabic numerals, e.g. Table 1. These should be double-spaced on separate pages with a title and short explanatory paragraph underneath.

9. Line drawings and photographs are numbered in sequence in arabic numerals, e.g. Fig. 1. If an illustration has more than one part, each should be identified as, e.g. 9A, B etc. They should be supplied as high resolution digital images either in separate files or on separate pages at the end of the manuscript: they should not be embedded in the text. A metric scale must be inserted in photomicrographs etc. Legends for illustrations should be typed on a separate page.

10. Authors should assure the Editor explicitly that all illustrations, including maps, do not infringe copyright law.

11. Articles should be submitted to the Editor: Dr Iain Wilkie by email Editor@gnhs.org.uk as a single word-processed document. Photographs and illustrations should be high resolution with a minimum of 300 dpi in tif or jpeg format.

12. When the article is accepted for publication, the author should return the corrected manuscript to the Editor as soon as possible. Final proofs will be emailed to authors and should be returned by email as soon as possible. Alterations at this stage should be kept to the correction of typographical or formatting errors. More extensive alterations may be charged to the author.

13. A copy of the published article will be sent to the first author as a pdf file. Offprints will not be supplied.

14. All submissions are liable to assessment by the Editor for ethical considerations, and publication may be refused on the recommendation of the Editorial Committee.

15. Authors must sign a publishing agreement giving the GNHS copyright for articles published in *The Glasgow Naturalist*. This is standard procedure for publishing in most scientific journals, and allows the article to be archived at the Biodiversity Heritage Library https://www.biodiversitylibrary.org/bibliography/38981#/